



THE  
ONTARIO WATER RESOURCES  
COMMISSION  
  
BASIC COURSE  
  
FOR  
  
SEWAGE WORKS OPERATORS

1969

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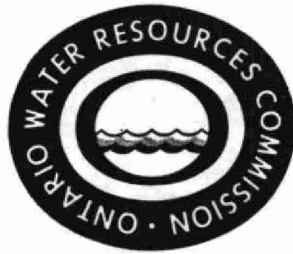
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**BASIC COURSE**

**FOR**

**SEWAGE WORKS OPERATORS**

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SEW  
APXL apxl

Ontario Water Resources Commission  
Sewage Operators' Courses

Course I

Basic	1961	
Basic - repeat	1961	October 16-20th
Intermediate	1962	March 5-9th
Intermediate - repeat	1962	December 10-14th
Senior	1963	April 22-26th
Senior - repeat	1963	September 16-20th

Course II

Basic	1963	November 18-23rd
Intermediate	1964	May 25-29th
Senior	1964	December 7-11th

Course III

Basic	1965	May 31 - June 4th
Intermediate	1965	December 6-10th
Senior	1966	April 25-29th

Course IV

Basic	1966	December 5-9th
Intermediate	1967	May 15-19th
Senior	1967	December 4-8th

Course V

Basic	1968	June 17-21st
Intermediate	1968	December 2-6th
Senior	1969	June 9-13th

Course VI

Basic	1969	December 8-12th
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ONTARIO WATER RESOURCES COMMISSION  
BASIC SEWAGE WORKS OPERATORS' COURSE

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SEWAGE WORKS OPERATORS' COURSE  
ONTARIO WATER RESOURCES COMMISSION

INTRODUCTORY STATEMENT BY MR. D. S. CAVERLY  
GENERAL MANAGER, OWRC.

It is being increasingly recognized today that training must be an on-going programme. New ideas, new techniques, new situations all demand that we take advantage of every opportunity to become better informed in our areas of responsibility.

The Sewage Works Operators' Course is designed to that end. Introduced by the Commission in 1961, it serves a most useful purpose in the further training of plant operators.

May I take this opportunity, first of all, to welcome you to this course. I know that you will take full advantage of it. There will be opportunities for you not only to hear lectures and take part in discussions on subjects of direct interest to you, but you will also see some laboratory work and demonstrations in what is considered to be one of the finest water resources laboratories in the country.

THE ONTARIO WATER RESOURCES COMMISSION

Before discussing the contents of the course and matters related to it, I would like to tell you something about the OWRC and its objectives. The OWRC is a relatively new organization in the Province of Ontario. It is involved in a programme of major significance insofar as the development of this Province is concerned. It has a close relationship with other departments and agencies in the Province, and it is desirable that its functions and organization be understood in order to appreciate the nature of the work which it is attempting to do.

Formerly, the supervision of water works and sewage works in this Province came under the Department of Health and, more particularly, under that Department's Sanitary Engineering Division. When the Ontario Water Resources

Commission was established by legislation in 1956 this supervision was transferred from the Department of Health to the Commission. The legislation was amended in 1957 and in subsequent years as well, whenever the situation warranted it. The Commission is now operating under this 1957 legislation together with its amendments. While it is similar in some respects to legislation under the Public Health Act, it is considerably more far-reaching and gives the Commission wide authority to deal with sewage works and the problem of water pollution.

The Commission consists of six members, under whose direction policy is determined and the programme put into effect. The Commission maintains a staff of well trained personnel who act as advisers to municipalities and others throughout the Province. These men are specialists in a variety of fields relating to sewage and stream sanitation. It is hoped that there will always be close co-operation between the staff and the operators of sewage works. The papers given at this conference will be presented by members of the staff, and you will learn more about the activities of the Commission in this way. It is only through close co-operation between operators and the Commission that the best results can be obtained. The staff of the Commission are here to assist at all times in problems with may arise in the treatment of sewage and in the prevention of water pollution.

#### OBJECTIVES OF THE COURSE

It is well, at the outset of this course, to define objectives so that each will understand what is expected of him and what type of training is to be provided. Here is an unsurpassed opportunity for those in charge of sewage and waste treatment plants to learn about many subjects, to discuss problems with others in similar positions, and in that way, to have a full exchange of experience and ideas.

Our first objective is to train operators in the fundamentals of sewage plant operation. The programme of the Commission in pollution control can only be made effective if the operators are thoroughly trained and are alert to their



responsibilities. It is only possible in a course of this kind to deal with fundamental or basic subjects, but a thorough training in these will enable any operator to go further in his education and to learn much from day to day operation of his plant. Accordingly, primary subjects will be discussed in this first course, and more advanced material will come later.

This is a working course in which each person registered will be expected to apply himself diligently and to acquire as much as possible from the lectures and from the demonstrations to be given. It may be inconvenient for some to listen hour after hour to lectures, especially when they have not been accustomed to this, but there will be intermissions, and the changes in the subjects should overcome most difficulties of this nature.

The number of courses of instruction is expected to be three before a Certificate of Qualification is granted. The later courses will be more specialized and it may be desirable to break them up according to the kinds of works being done by each operator. Laboratory may be desired by some more than by others.

It should be made clear that this course is not given in preparation for a licencing system, although some such are in effect in the United States. These courses are intended to provide a qualification which will be recognized throughout this Province. The successful candidate, at the conclusion of the full set, will be given a certificate indicating that he is qualified in his field. Each person attending the courses should have had some experience in sewage plant operation. If he has been in this field for some time there will, no doubt, be a repetition of some information which is familiar to him. This must not be considered as objectionable, but rather as placing emphasis on it. It is hoped that criticisms and recommendations will come from the group, and that there can be discussions of the various subjects following their presentation. Legislation and procedures in effect in Ontario will be stressed.

## SUBJECTS OF THE COURSE

You will see that the timetable covers a wide variety of subjects. Emphasis is put on background information and on operating problems. Elementary laboratory tests are included, and as the courses advance there will be more of that. An examination will follow the completion of each course at the end of the week. The objective is not merely to teach the operator certain subjects but rather to stimulate his interest in his work, and to emphasize his importance in the overall scheme. The Commission is cognizant of the very important part which the operator plays in stream sanitation.

## FUTURE COURSES AND EXAMINATION

The present plans are to have future courses at about six month intervals. Thus, a person starting this one would gradually advance to the next two. In addition, these primary courses will be repeated for those who have not been able to attend this one. Each municipality sending an operator is making an investment, and it is hoped that the returns will well justify the time and effort expended.

## CERTIFICATION OF OPERATORS

In days of competition and technical advances it is obvious that the operator who has obtained adequate training should be recognized in some tangible manner. Certification appears to be the best procedure. It is hoped that the certificates to be issued by the Commission to those obtaining qualification will be recognized throughout the municipalities of this Province and that they will become increasingly important, regardless of where the operator may work. This is in keeping with a plan for water works operators and for others in the field covered by the OWRC.

## READING AND SELF-TRAINING

No course of instruction can complete the education of an operator. This course is intended to act as a start and a stimulus to greater knowledge. It is thus hoped that the operator will follow conscientiously on the instruction given here, and will take advantage of reading from text books, magazines, and other publications. Continuous study is imperative to keep up with the rapid advances taking place in these techniques today.

## THE FOLLOW-UP PROGRAMMES

The foregoing will indicate the objectives of this training and the proposal for certification. It is also hoped that this information may be supplemented by further action to be taken by the OWRC and by the operators themselves. Some of these actions may be listed, as follows:

The Commission expects to publish, as soon as possible, the lectures given at this course. This material will serve as a reference, and each operator will be supplied with a copy which he is asked to keep on file and to study in full detail.

The operator can also acquire valuable information through an exchange of experience with others. The number of sewage treatment plants in the Province is growing steadily, and greater information is being accumulated on operating problems. A conference of this kind aids greatly in an exchange of information, apart from anything that is given in the lectures and in the laboratory work. Organizations which provide information for the operator can also be useful to him as are periodic meetings arranged among the operators themselves. Membership in an Organization such as the Canadian Institute on Pollution Control will prove another valuable aid to every plant operator.

It is desirable that there be a set of books and magazines at each sewage treatment plant. Many are published today, and if a wise selection is made they can prove to be exceedingly valuable to the operator in his daily problems.

The Commission publishes, on a fairly regular basis, research bulletins and other information which serves to keep the operator abreast of new developments, and there is also the contact in the field between the staff of the Commission and the operators as inspections are made of the plants.

One of the main features about any course of instruction is the incentive it creates in the minds of the students to acquire greater knowledge. This will rest with the individual. This course must assist him towards attaining this objective.

THE ROLE OF THE SEWAGE WORKS OPERATOR  
IN THE FIELD OF PUBLIC HEALTH

H. Browne  
Supervisor of Sewage Works  
Division of Sanitary Engineering

The proper operation of a sewage treatment plant is important in protecting the public health of any community. It is recognized that untreated sewage discharged to a stream can carry with it dangerous bacteria and viruses, which, if taken into a public water supply, may result in sickness or even in death to those who consume the water. It is essential, therefore, that operators of sewage treatment plants become acquainted with problems that they must meet in their every day work so that they may run plants to the best of their ability. There is, consequently, some responsibility in the protection of the public health of the community in the operation of a sewage disposal plant.

OPERATION OF SEWAGE PLANT BECOMING MORE DIFFICULT

There are many factors that make the operation of a sewage disposal plant more difficult and perplexing with each passing year as residential and industrial growth mushrooms, distances between sewage outfalls and water intakes become less and less and many complex, new and persistent types of pollutants complicate the situation. The discovery of new enteric viruses present in human wastes, and against which routine chlorination treatment has little effect, has caused additional concern. There is much to learn about new and changing problems in the field of sewage treatment that make the task of the operator increasingly more difficult.

### OPERATION OF SEWAGE PLANT NOT AN EASY TASK

The operation of a sewage disposal plant with its many complications is, therefore, not an easy task. There should be a greater appreciation by the general public and by elected representatives that there are no complete answers to many of the problems that an operator of a sewage treatment plant meets in his work from day to day. Everyone has heard the assurances of proponents of sewage plants that there will be no offensive odours in the atmosphere in the vicinity of a new sewage plant. Later, the operator is confronted with conditions such as gross overloading by residential growth and shock industrial loads, heavy infiltration on the sewerage system, foaming synthetic organics, inadequate receiving streams, improper design, unsuitable equipment, and a variety of other perplexing problems. It is, therefore, practically an impossibility that there will always be an odour-free atmosphere in the vicinity of a sewage plant. There should be a greater understanding of that fact, and also that a sewage plant operator works under trying circumstances in endeavouring to provide an assurance that is not based on reality.

### PLANT SHOULD BE OPERATED TO BEST OF ABILITY

It has been indicated that the sewage works operator has an important role in the protection of public health. It is his responsibility to operate the plant to minimize the pollution that reaches the receiving stream and the hazards to any water supplies or swimming areas. The condition of the receiving stream, and the possibility of adding contamination to it, should, therefore, be a foremost consideration in the operation of any sewage treatment plant. The operator should acquire sufficient training to meet problems that confront him from day to day. It must be recognized that there are certain problems that may require sewer or plant changes or extensions that are beyond the ability of the operator to provide. It is essential that these changes or extensions be provided before the operator can run the plant efficiently. The responsibility for the proper operation of a sewage plant is not the operator's alone.

## EMPLOYEE TRAINING FOR SEWAGE WORKS OPERATION

A well trained operator is definitely an asset if a sewage works plant is to function properly, but a conclusion that all operators without formal training are unable to operate treatment plants is basically wrong. Many operators through adequate initial instruction from their fellow operators and by studying the literature become quite able to operate their own or similar plants. It must be recognized, nevertheless, that the acquisition of training is of considerable value in operating any sewage plant with its myriad of problems.

## TYPES OF OPERATORS REQUIRED IN LARGE AND SMALL PLANTS

The operation of a large sewage plant requires a person in charge that has a knowledge of the mechanical, biological and chemical aspects of the treatment. As a result, one often finds an engineer supervising the mechanical details and a chemical engineer or bacteriologist in charge of the treatment. It is essential in the larger plants that both types of knowledge be available. In the smaller plants there is the need for an operator with mechanical ability who can acquire through reading and training courses the knowledge that is necessary to meet the problems that accrue. That is the basic reason for the establishment of the sewage operators' training course.

## TRAINING OPPORTUNITIES HAVE BEEN LIMITED

It is true that the opportunity for training for a sewage works operator has been more limited than for an operator in the water works field. Most sewage works operators have had to depend on correspondence schools or on reading to further their training. It is hoped, therefore, that the OWRC at this course and in the future may be able to provide some measure of training at its schools. This will permit a sewage works operator to acquire knowledge on problems that may arise and also the methods employed and the agencies available to him in correcting the conditions that do materialize.



MAIN ESSENTIAL TO GOOD OPERATION

The main essential to good operation is that the operator of a sewage plant have some basic mechanical or technical training so that he can operate the plant to the best of his ability. The operator must also have the facilities to do his job and understand the limitations of his plant. He should have an appreciation of the fact that bacteria or viruses dangerous to humans can readily go through the sewage plant and that precautions are required if there is any swimming area or water supply that may be endangered in the vicinity of the sewage plant outfall.

SHOULD OPERATE PLANTS TO MAINTAIN OBJECTIVES OF  
WATER QUALITY IN RECEIVING STREAM

It must be recognized that sewage treatment does not completely disinfect the effluent that is discharged from a sewage plant. Therefore, an operator cannot hope to produce an effluent that will not constitute some hazard to the receiving stream. All he can do is to operate the plant to maintain the stream to a standard that will suit the conditions in the area. Often these standards have not been set but are designated as objectives rather than precise standards. The objectives in Ontario require that the treatment be sufficient for adequate removal or reduction of solids, bacteria and chemical constituents which may interfere unreasonably with the use of the receiving water for domestic water supply, bathing, and fish and wild life. It is considered that adequate protection for these waters will be provided if the coliform M.P.N. median value does not exceed 2,400 per 100 ml. at any point in the waters following initial dilution and if the suspended solids and 5-day BOD of the discharge are not both in excess of 15 ppm. It must be recognized that this will require secondary treatment in order to achieve these objectives. It must be agreed that in certain specific instances influenced by local conditions that even these objectives must be exceeded, if the receiving stream is inadequate in flow or if there is any immediate danger to a swimming area or water works intake. The provision of effluent filters and of chlorination may then be required to assure a safer effluent. Disinfection of effluent is arbitrarily defined



as the addition of sufficient chlorine so that a chlorine residual of 0.5 ppm is present 15 minutes after the chlorine is applied. The point of chlorine application must be such that the entire flow of sewage can be chlorinated and be held for 15 minutes before discharge to the receiving stream. On the other hand, there are many plants that have adequate diluting water in the receiving stream and have, therefore, been designed for primary treatment. At such plants the objectives for receiving stream water permit higher suspended solids and 5-day BOD contents. Chlorination may or may not be required, dependent on the danger to water supplies or swimming areas below the outfall.

#### OPERATOR SHOULD KNOW OBJECTIVES FOR RECEIVING STREAM WATER

The sewage works operator should then ascertain the objectives that he must maintain to keep the receiving stream in a suitable condition. These objectives vary because of many factors such as, the type of plant, the location of nearby water works plants or swimming areas, large industries in the area using quantities of process water, beach areas that must be protected, algae growths and other conditions. Studies are necessary to determine the degree of treatment that is required to maintain the objectives for water quality in the receiving stream. Every effort should be made to operate the plant so that these objectives can be maintained.

#### BY-PASSING OF SEWAGE SHOULD BE AVOIDED

It is basic that by-passing of sewage from a plant should be kept to a minimum. It is recognized that at the time of storms the excess flow beyond two and one-half times the dry weather flow will be by-passed and that on occasion the operator is confronted with a maintenance problem that will require by-passing of sewage. However, deliberate by-passing because of problems in operation should be avoided if at all possible. Every effort should be made to solve the problem before resorting to by-passing. In many cases the correction may require the aid of outside authorities to find the solution. Such aid should be sought. In other

problems it may require the provision of additional facilities either on the sewerage system or at the plant. The attention of local officials responsible for providing such improvements should be drawn to the need for their installation.

#### BY-PASSING OF SEWAGE IN WINTER OR AT RUN-OFF PERIODS

A sewage plant operator should appreciate that sewage solids deposited on the bottom of the stream during winter may exert an oxygen requirement for a long time. Discharges of sludge in winter and at spring run-off periods may solve several problems at the plant but may cause adverse conditions in the receiving stream long after the by-passing has taken place. The plant should, therefore, be operated so that no heavy by-passing of sewage or discharge of sludge is made at times that are not suitable for such discharges. Such by-passing can definitely affect the receiving stream to a marked degree although it may not be evident at the time.

#### SUPERVISION OF CHLORINATION AT CERTAIN TIMES IN THE YEAR

A major protection to the public health of any community is proper chlorination of the sewage plant effluent. If chlorination has been installed in a plant, it has been required as an added safeguard. Therefore, if the operator neglects to maintain a proper residual he is reducing the protection that the treatment provides. It is true that research will have to find the answer and assess the public health significance of the growing array of new-type enteric viruses and synthetic organics that do not break down like natural organics. The operator can only wait for research to determine the answers to such complex questions. However, he has the answer to the reduction of well known diseases such as typhoid, paratyphoid and dysentery by effective chlorination. He can at least protect the public from such diseases by operating his plant and, in particular, the chlorination equipment to the correct standards. The need for chlorination in off-swimming months is one that should be decided on the basis of the conditions in the area. If the treatment is required only to protect a swimming area then chlorination can be suspended. If it is required to

protect a water supply it should be continued at all times. It is generally recognized that the organism which causes typhoid fever lives longer in cold water than in warm water. Consequently, it is apparent that chlorination should be continued to protect the water supply below the outfall.

#### SIGNIFICANCE OF FISH KILL

It is true that the fish and wild life of a stream are not important from the standpoint of public health. Yet, there is nothing outside of offensive odours from a sewage plant that will raise the ire of the general public more than a fish kill in the receiving stream. It is gratifying to learn, therefore, that effluents from sewage plants rarely cause fish kills. According to the first nation-wide survey made in the United States, effluents from sewage plants accounted for only eight per cent of the total fish kills. Agricultural poisons from run-off of fertilized lands accounted for forty per cent of the total, and industrial wastes for thirty-one per cent. In all probability, if a fish kill takes place, it is not caused by the sewage plant effluent unless it contains a toxic industrial constituent or the oxygen in the receiving stream is depleted by a heavy discharge of sludge or sewage at one time. There is more danger from independent industrial waste discharges and from fertilizers used on the land.

#### SIGNIFICANCE OF PROLIFIC ALGAE GROWTHS

The existence of prolific growths of algae in the receiving streams has caused concern in recent years. These growths may or may not be located in the vicinity of sewage works outfalls. If they are there is little doubt that the sewage effluent provides some measure of fertilization for the growths. An improvement in the treatment at the sewage plant will not reduce these growths; in fact, it may increase them. The answer to the problems, therefore, does not rest with the operator. It will come in the research being carried out on improved sewage treatment and the use of algicides to eliminate the algae. Some progress is being made in this research.

### SIGNIFICANCE OF NEW SYNTHETIC CONTAMINANTS

Sewage plants now receive an ever increasing amount of new-type synthetic chemical contaminants. These synthetic organics do not break down but persist over long periods of time. They are not removed either by sewage treatment or by normal water purification practices. They often cause concern and even consternation below sewage plant outfalls. Once again the answer to the problem does not lie with the operator of the plant. There is much to learn about the behaviour of these new contaminants and their long range subtle effects on public health, on aquatic growths and on municipal water supplies. Research must find the answer for these synthetic pollutants just as for prolific algae growths before the operator can take definite action to eliminate them.

### OPERATOR SHOULD HAVE FACILITIES TO DO WORK PROPERLY

It is important that the sewage works operator have the facilities to operate the plant properly if he is to provide the supervision that is required. In many municipalities the design of a sewage plant is cheapened due to economic factors so that facilities to meet each condition are not available. Yet the general public is unaware of this condition and expects the operator to be able to turn out a good effluent from the plant and to keep the area free from odours at all times. It is true that the sewage works operator will usually give careful responsible supervision, but often he will find conditions created that are beyond his, or anyone else's, capability to correct because of inadequacy in plant equipment or design.

### CONDITION THAT OVER TAX A SEWAGE PLANT

Conditions that can readily over tax the design, capacity and equipment of a plant are heavy infiltration on the sewerage system, septic conditions in the sewers or at the plant, heavy or shock industrial loads or overloading of the hydraulic designed capacity of the plant. If these conditions exist the operator should make them known to the inspecting authorities and to the responsible municipal

officials so as to achieve an improvement. If the operator does not receive such assistance he cannot provide proper operation for the plant.

#### LOCATION OF PLANT IS IMPORTANT IN TYPE OF OPERATION PROVIDED

An operator should evaluate the location of the sewage plant to points that require protection such as swimming areas, bathing beaches and water supplies. He should appreciate the public health significance if heavy contamination should reach those points. While careful operation is desired at every plant it is doubly required at plants that are potential dangers to the public.

#### PROTECTION OF THE OPERATOR'S HEALTH

There is one last point that is important in the protection of public health by the sewage plant operator. It is the protection of his own personal health. An operator must remember always that the flow through his plant may contain bacterial and virus infections that may cause him illness and even death. There is the danger from cuts that may result in tetanus, the hazard of drowning particularly when ice covers the walk-ways in winter, the threat of explosion and asphyxiation from poisonous accumulations of gas. The operation of a sewage plant is a hazardous occupation not an easy one. An operator should, therefore, take every precaution to avoid infection and should obey all safety rules to protect himself against explosions, drowning and asphyxiation. Be interested in public health protection, but do not forget your own health.

#### SUMMARY

The role of the sewage works operator in the field of public health can be summarized as follows:

- (1) He should obtain training so as to operate the plant to the best of his ability and to be aware of the limitations of the plant's design and equipment.

- (2) He should bring to the attention of the responsible authorities the limitations of his plant to meet problems so that they can plan and budget for improvements.
- (3) He should know the standards that he should reach at his plant to maintain the objectives for water quality in the receiving stream.
- (4) He should avoid by-passing of sewage or discharge of sludge to the receiving stream, whenever possible.
- (5) He should maintain the chlorine residual in the effluent at all times when such treatment is required.
- (6) He should learn the location of the swimming areas and water supplies in the area so that he can provide suitable protection to these areas or supplies.
- (7) He should take every precaution to protect his own health and welfare. The knowledge of safety is essential, therefore, for every operator.
- (8) He should realize that research still has to find the answer for many of the problems that cause difficulties in a sewage plant from day to day.
- (9) He should endeavour to establish and maintain good public relations.



BASIC MATHEMATICS

J. Stasiuk, P. Eng.

Engineer  
Division of Sanitary Engineering

An operator of a wastewater treatment plant should routinely evaluate the efficiency of the plant and of the individual units. In most activated sludge plants routine laboratory tests are performed daily to ensure that the plant is effectively tuned to operate under optimum conditions. The analyses determined in the laboratory will assist the operator in deciding whether any adjustments are necessary to the treatment units to achieve a high degree of efficiency of operation.

This necessitates that the operator be able to apply the laboratory data made available to him. It is essential that he has a good sound knowledge of basic mathematics to fully understand the significance of the results.

The object of this presentation is to help the student recollect some of the mathematics he learned at school and be able to apply it to the sewage treatment process. In addition, it will prepare the student to appreciate more fully the material to be presented in subsequent lectures of this course.

ARITHMETIC

Addition

The basic rule when adding numbers that have no decimals and which do not have the same number of digits (a single figure like 4, 7, 6, etc.) is to arrange them starting from the right hand side.

If the numbers contain units such as inches, feet, yards or pounds, etc., all the numbers must be changed to a similar unit before attempting the addition.

C - 2

Example: add 4 inches, 3014 inches, 68 inches and  
11,762 inches

$$\begin{array}{r} 4 \text{ inches} \\ 3014 \text{ inches} \\ 68 \text{ inches} \\ \underline{11762 \text{ inches}} \\ 18 \\ 13 \\ 7 \\ 4 \\ \underline{1} \\ 14848 \text{ inches} \end{array}$$

### Subtraction

Subtraction is literally the inverse of addition but the arrangement of numbers is similar when preparing to carry out the subtraction.

Example: subtract 7413 from 621

$$\begin{array}{r} 7413 \\ - 621 \\ \hline 6792 \end{array}$$

You can check your subtraction by adding the answer to the number being subtracted and the resulting answer should be the original or first number.

$$\begin{array}{r} 6792 \\ + 621 \\ \hline 7413 \end{array} \text{ checks with the first number above.}$$

You should develop a habit of mentally checking all your subtractions.

Example: subtract 8572 feet from 10,681 feet

$$\begin{array}{r} 10,681 \text{ feet} \\ - 8,572 \text{ feet} \\ \hline 2,109 \text{ feet} \quad (\text{answer}) \\ \underline{10,681 \text{ feet}} \quad (\text{check}) \end{array}$$



Multiplication

Multiplication is essentially the process of adding a certain number a given number of times.

$$3 + 3 + 3 + 3 + 3 + 3 + 3 = 3 \times 7 = 21$$

It would be helpful at this stage to be thoroughly familiar with your multiplication table. If you are not, you should spend some time reviewing it.

The mathematical terminology of multiplication is:

$$\begin{array}{rcl} \text{multiplicand} & \times & \text{multiplier} = \text{product} \\ 85 & \times & 31 = 2635 \end{array}$$

Example:

$$\begin{array}{r} 6231 \\ \times 42 \\ \hline 12462 \\ 24924 \\ \hline 261702 \end{array}$$

When multiplying two numbers, the units do not have to be identical. However, units as well as numbers have to be multiplied.

Example:

1. 4 yards x 8 yards = 32 (yds. x yds.) = 32 yds<sup>2</sup>
2. 8 acres x 2 inches = 16 acre-inches
3. It takes 6 men to complete a job in 8 hours. Therefore we can say it took (6 men x 8 hours) 48 man-hours to do the work.

Two points you should bear in mind are:

1. (any number) x 1 = the number
2. (any number) x 0 = 0

Example: 432 x 1 = 432

$$407 \times 0 = 0$$

Division

Division is the process of determining how many times one number is contained in another.

The mathematical notation is:

$$\frac{\text{divisor}}{\text{dividend}} \text{ quotient}$$

4 is contained in 8, 2 times

$$4 \overline{) 8} \begin{array}{r} 2 \\ \hline \end{array}$$

Example: divide 261,702 by 42

This may also be expressed as  $\frac{261,702}{42}$

or  $261,702 \div 42$

$$\begin{array}{r} 6231 \\ 42 \overline{) 261702} \\ \underline{252} \phantom{xxx} \\ 97 \\ \underline{84} \\ 130 \\ \underline{126} \\ 42 \\ \underline{42} \\ 0 \end{array}$$

The quotient (answer) is 6,231. In this case the divisor is contained in the dividend exactly 6,231 times. However, there could be a remainder as the following problem exemplifies.

Example: divide 8,472 by 76

$$\begin{array}{r} 111 \\ 76 \overline{) 8472} \\ \underline{76} \phantom{xx} \\ 87 \\ \underline{76} \\ 112 \\ \underline{76} \\ 36 \end{array}$$

answer: 111, remainder 36

The division can be checked by multiplying the divisor by the quotient and adding the remainder. This figure should check with the dividend if the computation was carried out correctly.

The following example illustrates a check of the above computation:

$$\begin{array}{r}
 111 \\
 \times 76 \\
 \hline
 666 \\
 777 \\
 \hline
 8436 \\
 + 36 \\
 \hline
 8472
 \end{array}$$

This answer checks with the original dividend therefore the answer is correct.

### FRACTIONS

A fraction is an expression of one or more parts of a unit or a whole number. The various rules in dealing with the different operations using fractions namely, addition, subtraction, multiplication are presented below. The upper number of a fraction is known as the numerator and the lower one a denominator.

That is:  $\frac{\text{numerator}}{\text{denominator}}$

### Cancellation

A useful principle to bear in mind regarding fractions is that the value of a fraction is not altered if the numerator and denominator are multiplied or divided by the same number. This principle is known as the principle of cancellation.

Example:  $\frac{2}{3} = \frac{2 \times 3}{3 \times 3} = \frac{6}{9}$

or  $\frac{6}{9} = \frac{6 \div 3}{9 \div 3} = \frac{2}{3}$

However, the same principle does not apply if the same number is added to or subtracted from the numerator and denominator of a fraction.

$$\frac{3}{4} \text{ does not equal } (\neq) \frac{3+2}{4+2} = \frac{5}{6}$$

$$\text{or } \frac{3}{4} \neq \frac{3-1}{4-1} = \frac{2}{3}$$

The concept of these fundamentals is one of the most useful tools when working with fractions.

### Addition and Subtraction

When fractions are to be added or subtracted it is necessary that the denominators of all fractions be identical. If they are not, we utilize the principles illustrated above. That is, we suitably change the numbers of the fraction without actually altering the value of the fraction and complete the required computation.

The least common denominator is the lowest number that both denominators will divide into with nothing left over. In the case of the addition or subtraction of fractions, this is the number we try to obtain in all denominators. We then perform the required calculation as indicated in the problem using the numerators and express the resultant numerator over the common denominator.

Example: calculate  $\frac{1}{2} + \frac{3}{4}$

The common denominator (the smallest number 2 and 4 divide into with no remainder) is 4. Express both fractions, without changing its value, having a denominator of 4.

$$\frac{1 \times 2}{2 \times 2} + \frac{3}{4} = \frac{2}{4} + \frac{3}{4}$$

Now complete the addition of the numerators and express the resultant numerator over the common denominator.

$$\frac{2}{4} + \frac{3}{4} = \frac{5}{4}$$

Example: calculate  $\frac{1}{3} + \frac{3}{5} - \frac{1}{10}$

The common denominator is 30 because 3, 5 and 10 all divide into it with no remainder.

$$\frac{1 \times 10}{3 \times 10} + \frac{3 \times 6}{5 \times 6} - \frac{1 \times 3}{10 \times 3}$$

$$\frac{10}{30} + \frac{18}{30} - \frac{3}{30} = \frac{28}{30} - \frac{3}{30} = \frac{25}{30}$$

Fractions are generally reduced to their simplest form.

$$\frac{25 \div 5}{30 \div 5} = \frac{5}{6}$$

In some examples a whole number will be associated with a fraction (mixed fraction i.e.  $4 \frac{7}{8}$ ) and before any calculations are executed this expression should be changed to the fractional form (improper fraction i.e.  $\frac{39}{8}$ ).

To change a mixed fraction to an improper fraction:

1. multiply the denominator by the whole number and add the result to the numerator.
2. express as an improper fraction by taking the result obtained in (1) as the numerator and the original denominator as the final denominator.

Example: express  $3 \frac{5}{8}$  as an improper fraction

$$\frac{(3 \times 8) + 5}{8} = \frac{29}{8}$$

### Multiplication

The procedure for multiplying fractions is to multiply the numerators for the new numerator and the denominators for the new denominator.

$$C - 8$$

Example: 1. compute  $\frac{3}{4} \times \frac{5}{8}$

$$\frac{3}{4} \times \frac{5}{8} = \frac{15}{32}$$

$$2. 1 \frac{3}{5} \times 2 \frac{1}{3}$$

$$\frac{(5 \times 1) + 3}{5} \times \frac{(3 \times 2) + 1}{3} = \frac{8}{5} \times \frac{7}{3}$$

$$= \frac{56}{15} = 56 \div 15 = 3 \frac{11}{15}$$

### Division

The procedure to follow when dividing fractions is to invert the divisor and multiply as described above.

Example: 1. invert the following numbers  $\frac{3}{5}$ ,  $\frac{1}{5}$  and 8

$$\frac{3}{5} \text{ answer } \frac{5}{3}$$

$$\frac{1}{5} \text{ answer } \frac{5}{1} = 5$$

$$8 \text{ answer } \frac{1}{8}$$

$$2. \frac{3}{5} \div \frac{4}{3}$$

invert the divisor, then multiply

$$\frac{3}{5} \times \frac{3}{4} = \frac{9}{20}$$

C - 9

$$3. \ 2 \frac{1}{2} \div 1 \frac{6}{7}$$

$$= \frac{5}{2} \div \frac{13}{7} = \frac{5}{2} \times \frac{7}{13}$$

$$= \frac{35}{26} = 11 \frac{11}{26}$$

### Ratio

Ratio is a term which will be referred to in future lectures of this course. It is defined as a mathematical statement of the comparison of two quantities having the same units and expressed in the form of a simple fraction. For example, if plant A has a capacity of 6 mgd and plant B a capacity of 2 mgd, the ratio of the capacities of plant A to plant B is

$$\frac{6 \text{ mgd}}{2 \text{ mgd}} = \frac{3}{1} \text{ or } 3:1$$

Example: If a 1 mgd primary plant costs \$300,000.00 and a 1 mgd conventional activated sludge plant costs \$500,000.00 what is the ratio of costs?

$$\frac{\text{cost of primary plant}}{\text{cost of activated sludge plant}} = \frac{300,000}{500,000} = \frac{3}{5} \text{ or } 3:5$$

### DECIMALS

A fraction could also be expressed in the decimal form. Decimals express fractions in multiples of 10, that is; tenths ( $\frac{1}{10} = 0.1$ ), hundredths ( $\frac{1}{100} = 0.01$ ) and thousandths ( $\frac{1}{1000} = 0.001$ ) etc.

C - 10

Example:      $\frac{2}{10}$  is 0.2

$\frac{2}{100}$  is 0.02

$\frac{2}{1000}$  is 0.002

One of the most common uses of decimals is evidenced in the Canadian monetary system. (50 cents is 0.50 of a dollar, 37 cents is  $\frac{37}{100}$  of a dollar or \$0.37).

The term "decimal places" designates the number of figures to the right of a decimal point in a number. For example, 0.0321 is expressed to four decimal places. We may also have numbers in front of the decimal point as in 437.672. A good practice to follow when there are no numbers to the left of the decimal point is to represent this case by placing a zero immediately in front of the decimal point i.e. 0.863.

### Adding and Subtracting Decimal Fractions

When arranging decimal fractions which are to be subtracted or added place the numbers in such a way that all the decimal points are in the same vertical column. If a number is shown with no decimal point, it is understood that a decimal point may be placed just to the right of the last figure in that number. That is, 383 is the same as 383.00. Annexing zeros after the last number of a decimal does not alter its value.

37.47 is the same as 37.4700

838 is the same as 838.000

Example: 1. add 431, 67.891, 24.37, 4, 0.010 and 3.125

431.000
67.891
24.370
4.000
0.010
3.125
<hr/>
530.396



2. subtract 624.315 from 38.24

$$\begin{array}{r}
 624.315 \\
 - 38.240 \\
 \hline
 586.075 \quad \text{answer} \\
 624.315 \quad \text{check}
 \end{array}$$

### Multiplication of Decimal Fractions

The multiplication is performed in the usual manner and the answer will contain as many decimal places as the sum of decimal places in the multiplicand and multiplier (the numbers just multiplied).

Example: perform the multiplication  $31.802 \times 6.51$

$$\begin{array}{r}
 31.802 \\
 \times 6.51 \\
 \hline
 31802 \\
 159010 \\
 190812 \\
 \hline
 20703102
 \end{array}$$

- a total of five decimal places in the numbers being multiplied

- a total of five decimal places in the product

### Division of Decimal Fractions

When dividing a number containing a decimal fraction by another decimal fraction the following procedure applies.

1. Count the number of decimal places the decimal has to be moved to the right to make the divisor a whole number.
2. Move the decimal point in the dividend the number of decimal points to the right (adding zeros if necessary) as in (1). Essentially, the numerator and denominator have been multiplied by the same number, therefore, not changing the value of the fraction.
3. Divide keeping the decimal point in the quotient directly above the decimal point in the dividend and the units above the corresponding units of the dividend.

Example: divide 11.36 by 3.2

In accordance with the rules above:

1. 3.2 becomes 32 (a whole number). We have multiplied it by 10.
2. We also move the decimal one decimal point to the right in the dividend so that, 11.36 becomes 113.6. We have also multiplied it by 10.

$$\begin{array}{r}
 3.55 \\
 32 \overline{) 113.60} \\
 \underline{96} \phantom{00} \\
 176 \phantom{00} \\
 \underline{160} \phantom{00} \\
 160 \phantom{00} \\
 \underline{160} \phantom{00} \\
 0
 \end{array}$$

$$\begin{array}{r}
 \text{check } 3.55 \\
 \times 32 \\
 \hline
 710 \\
 1065 \phantom{0} \\
 \hline
 113.60
 \end{array}$$

checks with original dividend  
therefore the answer is correct.

## PERCENT

Percent is a useful mathematical concept in any field since it gives one a clear comparison of efficiencies, loadings, etc. Literally "per" means "divided by" and "cent" means "hundred". Therefore, the whole is divided into 100 equal parts and the percent quoted is an expression of the part of the entire portion with which you are concerned. That is, 100% is the entire portion, 50% is one-half of the entire portion, 25% is one-quarter of the entire portion, 10% is one-tenth of the entire portion, etc.

Example: 1. What is 20% of 300

20% expressed as a fraction is  $\frac{20}{100}$

Therefore 20% is  $\frac{20}{100}$  or 0.20 of 300

$$0.20 \times 300 = 60$$

2. If a ton of sludge contains 90% water, what is the weight of water in the mixture.

one ton = 2,000 lb.

$$0.90 \times 2000 = \frac{90}{100} \times 2000 = 1800 \text{ lb. of water}$$

EXPONENTIAL NUMBERS

For ease of expression numbers are often stated in an exponential form. This is especially the case for very large or small numbers. It is the technique of stating a number or performing a mathematical operation with the number to the power of 10:

Notation

$10^0 = 1$	$10^{-1} = \frac{1}{10} = 0.10$
$10^1 = 10$	$10^{-2} = \frac{1}{100} = 0.01$
$10^2 = 100$	$10^{-3} = \frac{1}{1000} = 0.001$
$10^3 = 1,000$	$10^{-4} = \frac{1}{10000} = 0.0001$
$10^4 = 10,000$	$10^{-5} = \frac{1}{100000} = 0.00001$
$10^5 = 100,000$	$10^{-6} = \frac{1}{1000000} = 0.000001$
$10^6 = 1,000,000$	$10^{-7} = \frac{1}{10000000} = 0.0000001$

Rule 1. Any number to the power zero = 1

$$10^0 = 1$$

$$2^0 = 1$$

Rule 2. When numbers to a power of 10 are multiplied, the numbers are multiplied and the powers or exponents are added for the final answer.

$$3 \times 10^2 \times 2 \times 10^5 = 3 \times 2 \times 10^{5+2} = 6 \times 10^7$$

Rule 3. When two numbers to the power of 10 are divided, the numbers are divided and the exponent of the divisor is subtracted from the exponent of the dividend for the final answer.

$$\begin{aligned} & 9 \times 10^7 \div 3 \times 10^4 \\ &= \frac{9}{3} \times 10^{7-4} = 3 \times 10^3 \end{aligned}$$

Example: 1. express in the exponential form:

$$(a) 432 = 4.32 \times 100 = 4.32 \times 10^2$$

$$(b) 0.0461 = \frac{4.61}{100} = 4.61 \times 10^{-2}$$

$$(c) 2,000,000 = 2 \times 1,000,000 = 2 \times 10^6$$

2. perform the indicated mathematical operation:

$$(a) 3 \times 10^4 \times 7 \times 10^5 = (3 \times 7) 10^{(4+5)} = 21 \times 10^9$$

$$(b) 6.7 \times 10^{-2} \times 3.4 \times 10^7 = (6.7 \times 3.4) 10^{(-2+7)} \\ = 22.78 \times 10^5$$

$$(c) 4 \times 10^5 \div 2 \times 10^3 = \frac{4}{2} \times 10^{(5-3)} = 2 \times 10^2$$

$$(d) 7.5 \times 10^7 \div 2.5 \times 10^4 = \frac{7.5}{2.5} \times 10^{(7-4)} = 3 \times 10^3$$

## UNITS

A unit is the term of reference in a mathematical statement i.e. in the expression 3 feet the unit is feet, in 14 yards the unit is yards. It describes the form of measurement being used in the expression or computation.

The most common forms of measurement are the English and metric systems. The U.S. system is identical to the English one except for liquid measure. All of these systems are used in Canada. Consequently, we must be able to readily convert from one system to another.

Rule 1. Concrete numbers associated with a physical unit can be added or subtracted only when they all possess the same physical unit.

$$3 \text{ feet} + 2 \text{ yards} = 3 \text{ feet} + 6 \text{ feet} = 9 \text{ feet}$$

Rule 2. Concrete numbers, whether they have the same unit or not, can be multiplied or divided; however, a new unit is created since the units are subject to cancellation or multiplication.

Example: 1. solve

$$6 \text{ ft.} \times 3 \text{ ft.} = 18(\text{ft.} \times \text{ft.}) = 18 \text{ ft.}^2$$

2. A man drives 120 miles in 2 hours. At what speed is he driving?

$$\frac{120 \text{ miles}}{2 \text{ hours}} = 60 \text{ miles/hour}$$

$$1 \text{ hour} = 60 \text{ minutes}$$

$$3 \text{ hours} \left( \frac{60 \text{ minutes}}{\text{hour}} \right) = 180 \text{ minutes}$$

Note how the units are cancelled.

A conversion table is appended to this lecture to enable you to convert to the desirable unit system.

### PARTS PER MILLION

The term parts per million is used so extensively in the water and sewage works field to express analytical laboratory results that a complete section is devoted to its study.

Parts per million is a weight-to-weight ratio. It is used because of the high water dilution composing the sewage wastes. Basically, it is the weight of a substance, say in pounds, in one million pounds of the solvent.

If we have 10 lb. of chlorine contained in 1,000,000 lb. of water, the concentration of chlorine in water may be expressed as follows:

$$\frac{10 \text{ lb.}}{1,000,000 \text{ lb.}} = 10 \text{ ppm}$$

An important conversion factor to remember is:

$$1 \text{ ppm} = \frac{1 \text{ milligram}}{\text{litre}} = 1 \text{ mg/l}$$

Example: If we have a concentration of suspended solids (SS) of 15 ppm in a sewage effluent, approximately how many pounds of solids do we have in 100,000 gal. of sewage?

$$1 \text{ gal. of water} = 10 \text{ lb.}$$

It can be assumed that 1 gal. of sewage = 10 lb.

$$1 \text{ ppm} = \frac{1 \text{ lb.}}{100,000 \text{ gal.}}$$

$$\text{Concentration of solids} = 15 \text{ ppm} = \frac{15 \text{ lb.}}{100,000 \text{ gal.}}$$

Therefore, we have 15 lb. of suspended solids for every 100,000 gallons of sewage.

## CONCLUSION

The operator should become very familiar with the mathematics just covered. It may be necessary to refer to mathematics texts for a more complete coverage. Nevertheless, in subsequent lectures of mathematics if one is to proceed at an expected rate of progress it must be assumed that he is thoroughly capable of solving mathematical problems covering the topics discussed in this lecture.

One final word of instruction is that when the operator is solving a mathematical problem he should mentally know in what range of magnitude to expect the answer. A common error is misplacing the decimal point in the final solution. When the

problem has been solved, ask yourself: Does the answer make sense? It may save you from some embarrassing moments later when the answer is being quoted to your superiors.

In future lectures algebra and geometry will be discussed in relation to sewage treatment. Operators should prepare themselves for these lectures by reviewing these branches of mathematics prior to the next course.

# CONVERSION UNITS

Multiply	By	To Obtain
ACRES.....	160.....	Square rods
Acres.....	4840.....	Square yards
Acres.....	43.560.....	Square feet

ACRES INCHES.....27,154.....Gallons

ACRES INCH/HR.....452.....GPM

## ATMOSPHERES (STD.)

760 MM of Mercury  
at 32°F.....14.696.....Lbs./sq. inch

ATMOSPHERES.....	76.0.....	Cms. of mercury
Atmospheres.....	29.92.....	Inches of mercury
Atmospheres.....	33.90.....	Feet of water
Atmospheres.....	1.0333.....	Kgs./sq. cm.
Atmospheres.....	14.70.....	Lbs./sq inch
Atmospheres.....	1.058.....	Tons/sq. ft.
BARRELS-OIL.....	42.....	Gallons-Oil

## BARRELS

(Beer).....	31.5.....	Gallons
(Wine).....	31.0.....	Gallons

BRIT. THERM. UNITS.....	0.2520.....	Kilogram-calories
Brit. Therm. Units.....	777.5.....	Foot-lbs.
Brit. Therm. Units.....	$3.927 \times 10^{-4}$ .....	Horse-power-hrs.
Brit. Therm. Units.....	107.5.....	Kilogram-meters
Brit. Therm. Units.....	$2.928 \times 10^{-4}$ .....	Kilowatt-hrs.

B.T.U./MIN.....	12.96.....	Foot-lbs./sec.
B.T.U./min.....	0.02356.....	Horse-power
B.T.U./min.....	0.01757.....	Kilowatts
B.T.U./min.....	17.57.....	Watts

CENTARES (CENTIARES) 1.....Square meters

CENTIGRAMS.....0.01.....Grams

CENTILETERS.....0.01.....Liters

CENTIMETERS.....	0.3937.....	Inches
Centimeters.....	0.03280.....	Feet
Centimeters.....	0.01.....	Meters
Centimeters.....	10.....	Millimeters

CENTIMTRS. OF MERC.....	0.01316.....	Atmospheres
Centimtrs. of merc.....	0.4461.....	Feet of water
Centimtrs. of merc.....	136.0.....	Kgs./sq. meter
Centimtrs. of merc.....	27.85.....	Lbs./sq. ft.
Centimtrs. of merc.....	0.1934.....	Lbs./sq. inch

CENTIMTRS./SECOND.....	1.969.....	Feet/min.
Centimtrs./second.....	0.03281.....	Feet/sec.
Centimtrs./second.....	0.036.....	Kilometers/hr.
Centimtrs./second.....	0.6.....	Meters/min.
Centimtrs./second.....	0.02237.....	Miles/hr.
Centimtrs./second.....	$3.728 \times 10^{-4}$ .....	Miles/min.

CMS./SEC./SEC.....0.03281.....Feet/sec./sec.

CUBIC CENTIMETERS.....	$3.531 \times 10^{-5}$ .....	Cubic feet
Cubic centimeters.....	$6.102 \times 10^{-2}$ .....	Cubic inches
Cubic centimeters.....	$10^{-6}$ .....	Cubic meters
Cubic centimeters.....	$1.308 \times 10^{-6}$ .....	Cubic yards
Cubic centimeters.....	$2.642 \times 10^{-4}$ .....	Gallons
Cubic centimeters.....	$10^{-3}$ .....	Liters
Cubic centimeters.....	$2.113 \times 10^{-3}$ .....	Pints (liq.)
Cubic centimeters.....	$1.057 \times 10^{-3}$ .....	Quarts. (liq.)

Multiply	By	To Obtain
CUBIC FEET.....	$2.832 \times 10^4$ .....	Cubic cms.
Cubic feet.....	1728.....	Cubic inches
Cubic feet.....	0.02832.....	Cubic meters
Cubic feet.....	0.03704.....	Cubic yards
Cubic feet.....	7.48052.....	Gallons U.S.
Cubic feet.....	6.23.....	Imper. Gallons
Cubic feet.....	28.32.....	Liters
Cubic feet.....	59.84.....	Pints (liq.)
Cubic feet.....	29.92.....	Quarts (liq.)

CUBIC FEET/MINUTE.....	472.0.....	Cubic cms./sec.
Cubic feet/minute.....	0.1247.....	Gallons/sec.
Cubic feet/minute.....	0.4720.....	Liters/sec.
Cubic feet/minute.....	62.43.....	Lbs. of water/min.

CUBIC FEET/SECOND.....	0.646317.....	Million gals./day
Cubic feet/second.....	448.831.....	Gallons/min.

CUBIC FOOT WATER.....	62.4.....	Pounds
Cubic foot water.....	998.8.....	Ounces
Cubic foot water.....	28.315.....	Kilograms

CUBIC INCHES.....	16.39.....	Cubic centimeters
Cubic inches.....	$5.787 \times 10^{-4}$ .....	Cubic feet
Cubic inches.....	$1.639 \times 10^{-5}$ .....	Cubic meters
Cubic inches.....	$2.143 \times 10^{-5}$ .....	Cubic yards
Cubic inches.....	$4.329 \times 10^{-3}$ .....	Gallons
Cubic inches.....	$1.639 \times 10^{-2}$ .....	Liters
Cubic inches.....	0.03463.....	Pints (liq.)
Cubic inches.....	0.01732.....	Quarts (liq.)

CUBIC METERS.....	$10^6$ .....	Cubic centimeters
Cubic meters.....	35.31.....	Cubic feet
Cubic meters.....	61,023.....	Cubic inches
Cubic meters.....	1.308.....	Cubic yards
Cubic meters.....	264.2.....	Gallons U.S.
Cubic meters.....	220.....	Imperial Gallons
Cubic meters.....	$10^3$ .....	Liters
Cubic meters.....	2113.....	Pints (liq.)
Cubic meters.....	1057.....	Quarts (liq.)

CUBIC YARDS.....	$7.646 \times 10^5$ .....	Cubic centimeters
Cubic yards.....	27.....	Cubic feet
Cubic yards.....	46,656.....	Cubic inches
Cubic yards.....	0.7646.....	Cubic meters
Cubic yards.....	202.0.....	Gallons
Cubic yards.....	764.6.....	Liters
Cubic yards.....	1616.....	Pints (liq.)
Cubic yards.....	807.9.....	Quarts (liq.)

CUBIC YARDS/MIN.....	0.45.....	Cubic feet/sec.
Cubic yards/min.....	3.367.....	Gallons/sec.
Cubic yards/min.....	12.74.....	Liters/sec.

DECIGRAMS.....0.1.....Grams

DECILITERS.....0.1.....Liters

DECIMETERS.....0.1.....Meters

DEGREES (ANGLE).....	60.....	Minutes
Degrees (angle).....	0.01745.....	Radians
Degrees (angle).....	3600.....	Seconds

DEGREES/SEC.....	0.01745.....	Radians/sec.
Degrees/sec.....	0.1667.....	Revolutions/min.
Degrees/sec.....	0.002778.....	Revolutions/sec.

DEKAGRAMS.....10.....Grams



# CONVERSION UNITS

Multiply	By	To Obtain	Multiply	By	To Obtain
DEKALITERS	10	Liters	GALS. WATER (IMP.)	10.02	Pounds
DEKAMETERS	10	Meters	Gals. water (Imp.)	4.54	Kilograms
DRAMS	27.31375	Grains	GALLONS/MIN.	$2.228 \times 10^{-3}$	Cubic feet/sec.
Drams	0.0625	Ounces	Gallons/min.	0.06308	Liters/sec.
Drams	1.771845	Grams	Gallons/min.	8.0208	Cu. ft./hr.
FATHOMS	6	Feet	GALLONS WATER/MIN.	6.0086	Tons water/24 hrs.
FEET	30.48	Centimeters	GRAINS (TROY)	1	Grains (avoir.)
Feet	12	Inches	Grains (troy)	0.06480	Grams
Feet	0.3048	Meters	Grains (troy)	0.04167	Pennyweights (troy)
Feet	1/3	Yards	Grains (troy)	$2.0833 \times 10^{-3}$	Ounces (troy)
FEET OF WATER	0.02950	Atmospheres	GRAINS/U.S. GAL.	17.118	Parts/million
Feet of water	0.8826	Inches of mercury	Grains/U.S. gal.	142.86	Lbs./million gal.
Feet of water	0.03048	Kgs./sq. cm.	GRAINS/IMP. GAL.	14.286	Parts/million
Feet of water	62.43	Lbs./sq. ft.	GRAMS	980.7	Dynes
Feet of water	0.4335	Lbs./sq. inch	Grams	15.43	Grains
FEET/MIN.	0.5080	Centimeters/sec.	Grams	$10^{-3}$	Kilograms
Feet/min.	0.01667	Feet/sec.	Grams	$10^{-3}$	Milligrams
Feet/min.	0.01829	Kilometers/hr.	Grams	0.03527	Ounces
Feet/min.	0.3048	Meters/min.	Grams	0.03215	Ounces (troy)
Feet/min.	0.01136	Miles/hr.	Grams	$2.205 \times 10^{-3}$	Pounds
FEET/SEC./SEC.	30.48	Cms./sec./sec.	GRAMS/CM.	$5.600 \times 10^{-3}$	Pounds/inch
Feet/sec./sec.	0.3048	Meters/sec./sec.	GRAMS/CU. CM.	62.43	Pounds/cubic foot
FOOT-POUNDS	$1.286 \times 10^{-3}$	Br. Thermal Units	Grams/cu. cm.	0.03613	Pounds/cubic inch
Foot-pounds	$5.050 \times 10^{-7}$	Horse-power-hrs.	GRAMS/LITER	58.417	Grains/gal.
Foot-pounds	$3.241 \times 10^{-4}$	Kilogram-calories	Grams/liter	8.345	Pounds/1000 gals.
Foot-pounds	0.1383	Kilogram-meters	Grams/liter	0.062427	Pounds/cubic foot
Foot-pounds	$3.766 \times 10^{-7}$	Kilowatt-hrs.	Grams/liter	1000	Parts/million
FOOT-POUNDS/MIN.	$1.286 \times 10^{-3}$	B. T. Units/min.	HECTOGRAMS	100	Grams
Foot-pounds/min.	0.01667	Foot-pounds/sec.	HECTOLITERS	100	Liters
Foot-pounds/min.	$3.030 \times 10^{-5}$	Horse-power	HECTOMETERS	100	Meters
Foot-pounds/min.	$3.241 \times 10^{-4}$	Kg.-calories/min.	HECTOWATTS	100	Watts
Foot-pounds/min.	$2.260 \times 10^{-5}$	Kilowatts	HORSE-POWER	42.44	B. T. Units/min.
FOOT-POUNDS/SEC.	$7.717 \times 10^{-2}$	B. T. Units/min.	Horse-power	33,000	Foot-lbs./min.
Foot-pounds/sec.	$1.818 \times 10^{-3}$	Horse-power	Horse-power	550	Foot-lbs./sec.
Foot-pounds/sec.	$1.945 \times 10^{-2}$	Kg.-calories/min.	Horse-power	1.014	H-power (Metric)
Foot-pounds/sec.	$1.356 \times 10^{-3}$	Kilowatts	Horse-power	10.70	Kg.-calories/min.
GALLONS	3785	Cubic centimeters	Horse-power	0.7457	Kilowatts
Gallons	0.1337	Cubic feet	Horse-power	745.7	Watts
Gallons	231	Cubic inches	HORSE-POWER (BOILER)	33,479	B. T. U./hr.
Gallons	$3.785 \times 10^{-3}$	Cubic meters	Horse-power (boiler)	9.803	Kilowatts
Gallons	$4.951 \times 10^{-3}$	Cubic yards	HORSE-POWER-HOURS	2547	Br. Thermal Units
Gallons	128	Fluid ounces	Horse-power-hours	$1.98 \times 10^6$	Foot-lbs.
Gallons	3.785	Liters	Horse-power-hours	641.7	Kilogram-calories
Gallons	8	Pints (liq.)	Horse-power-hours	$2.737 \times 10^5$	Kilogram-meters
Gallons	4	Quarts (liq.)	Horse-power-hours	0.7457	Kilowatt-hours
GALLONS, IMPERIAL	1.20095	U.S. Gallons	INCHES	2.540	Centimeters
Gallons, U.S.	0.83267	Imperial gallons	Inches	25.4	Millimeters
Gallons Imperial	277.3	Cubic inches	Inches	0.0254	Meters
Gallons Imperial	0.16	Cubic foot	Inches	0.0833	Foot
Gallons Imperial	4.546	Liters	INCHES OF MERCURY	0.03342	Atmospheres
Gallons Imperial	0.00454	Cubic meter	Inches of mercury	1.133	Feet of water
GALLONS WATER	8.3453	Pounds of water			
GALS. WATER (U.S.)	3.785	Kilograms			

# CONVERSION UNITS

Multiply	By	To Obtain
Inches of mercury.....	0.03453.....	Kgs./sq. cm.
Inches of mercury.....	70.73.....	Lbs./sq. ft.
Inches of mercury.....	0.4912.....	Lbs./sq. inch
INCHES OF WATER.....	0.002458.....	Atmospheres
Inches of water.....	0.07355.....	Inches of mercury
Inches of water.....	0.002540.....	Kgs./sq. cm.
Inches of water.....	0.5781.....	Ounces/sq. inch
Inches of water.....	5.202.....	Lbs./sq. foot
Inches of water.....	0.03613.....	Lbs./sq. inch
KILOGRAMS.....	980,665.....	Dynes
Kilograms.....	2.205.....	Lbs.
Kilograms.....	1.102x10 <sup>-3</sup> .....	Tons (short)
Kilograms.....	10 <sup>3</sup> .....	Grams
KGS./METER.....	0.6720.....	Lbs. foot
KGS./SQ. CM.....	0.9678.....	Atmospheres
Kgs./sq. cm.....	32.81.....	Feet of water
Kgs./sq. cm.....	28.96.....	Inches of mercury
Kgs./sq. cm.....	2048.....	Lbs./sq. foot
Kgs./sq. cm.....	14.22.....	Lbs./sq. inch
KGS./SQ. MILLIMETER.....	10 <sup>6</sup> .....	Kgs./sq. meter
KILOLITERS.....	10 <sup>3</sup> .....	Liters
KILOMETERS.....	10 <sup>3</sup> .....	Centimeters
Kilometers.....	3281.....	Feet
Kilometers.....	10 <sup>3</sup> .....	Meters
Kilometers.....	0.6214.....	Miles
Kilometers.....	1094.....	Yards
KILOMETERS/HR.....	27.78.....	Centimeters/sec.
Kilometers/hr.....	54.68.....	Feet/min.
Kilometers/hr.....	0.9113.....	Feet/sec.
Kilometers/hr.....	0.5396.....	Knots
Kilometers/hr.....	16.67.....	Meters/min.
Kilometers/hr.....	0.6214.....	Miles/hr.
KMS./HR./SEC.....	27.78.....	Cms./sec./sec.
Kms./hr./sec.....	0.9113.....	Ft./sec./sec.
Kms./hr./sec.....	0.2778.....	Meters/sec./sec.
KILOWATTS.....	56.92.....	B. T. Units/min.
Kilowatts.....	4.425x10 <sup>4</sup> .....	Foot-lbs./min.
Kilowatts.....	737.6.....	Foot-lbs./sec.
Kilowatts.....	1.341.....	Horse-power
Kilowatts.....	14.34.....	Kg.-calories/min.
Kilowatts.....	10 <sup>3</sup> .....	Watts
KILOWATT-HOURS.....	3415.....	Br. Thermal Units
Kilowatt-hours.....	2.655x10 <sup>6</sup> .....	Foot-lbs.
Kilowatt-hours.....	1.341.....	Horse-power-hrs.
Kilowatt-hours.....	860.5.....	Kilogram-calories
Kilowatt-hours.....	3.671x10 <sup>3</sup> .....	Kilogram-meters
LITERS.....	10 <sup>3</sup> .....	Cubic centimeters
Liters.....	0.03531.....	Cubic feet
Liters.....	61.02.....	Cubic inches
Liters.....	10 <sup>-2</sup> .....	Cubic yards
Liters.....	1.308x10 <sup>-3</sup> .....	Cubic meters
Liters.....	0.2642.....	Gallons
Liters.....	2.113.....	Pints (liq.)
Liters.....	1.057.....	Quarts (liq.)
LITERS/MIN.....	5.886x10 <sup>-4</sup> .....	Cubic ft./sec.
Liters/min.....	4.403x10 <sup>-3</sup> .....	Gals./sec.

Multiply	By	To Obtain
LUMBER WIDTH (IN.) X THICKNESS (IN.).....	Length (ft.)	Board Feet
12		
METERS.....	100.....	Centimeters
Meters.....	3.281.....	Feet
Meters.....	39.37.....	Inches
Meters.....	10 <sup>-3</sup> .....	Kilometers
Meters.....	10 <sup>3</sup> .....	Millimeters
Meters.....	1.094.....	Yards
METERS/MIN.....	1.667.....	Centimeters/sec.
Meters/min.....	3.281.....	Feet/min.
Meters/min.....	0.05468.....	Feet/sec.
Meters/min.....	0.06.....	Kilometers/hr.
Meters/min.....	0.03728.....	Miles/hr.
METERS/SEC.....	196.8.....	Feet/min.
Meters/sec.....	3.281.....	Feet/sec.
Meters/sec.....	3.6.....	Kilometers/hr.
Meters/sec.....	0.06.....	Kilometers/min.
Meters/sec.....	2.237.....	Miles/hr.
Meters/sec.....	0.03728.....	Miles/min.
METRIC TONS.....	2204.6.....	Pounds
Metric tons.....	1.1023.....	Short tons
MICRONS.....	10 <sup>-6</sup> .....	Meters
MILES.....	1.609x10 <sup>5</sup> .....	Centimeters
Miles.....	5280.....	Feet
Miles.....	1.609.....	Kilometers
Miles.....	1760.....	Yards
MILES/HR.....	44.70.....	Centimeters/sec.
Miles/hr.....	88.....	Feet/min.
Miles/hr.....	1.467.....	Feet/sec.
Miles/hr.....	1.609.....	Kilometers/hr.
Miles/hr.....	0.8684.....	Knots
Miles/hr.....	26.82.....	Meters/min.
MILES/MIN.....	2682.....	Centimeters/sec.
Miles/min.....	88.....	Feet/sec.
Miles/min.....	1.609.....	Kilometers/min.
Miles/min.....	60.....	Miles/hr.
MILLIERS.....	10 <sup>3</sup> .....	Kilograms
MILLIGRAMS.....	10 <sup>-3</sup> .....	Grams
MILLILITERS.....	10 <sup>-3</sup> .....	Liters
MILLIMETERS.....	0.1.....	Centimeters
Millimeters.....	0.03937.....	Inches
MILLIGRAMS/LITER.....	1.....	Parts/million
MILLION GALS./DAY.....	1.54723.....	Cubic ft./sec.
MINER'S INCHES.....	1.5.....	Cubic ft./min.
Miner's inches.....	11.25.....	G.P.M. (Arizona, Cal., Mont., Nevada, Oregon)

# CONVERSION UNITS

Multiply	By	To Obtain	Multiply	By	To Obtain
(Idaho, Kansas, Neb., N.M., N.D., S.D., Utah)	9	G.P.M.	POUNDS/CUBIC INCH	27.68	Grams/cubic cm.
			Pounds/cubic inch	$2.768 \times 10^{-4}$	Kgs./cubic meter
			Pounds/cubic inch	1728	Lbs./cubic foot
MINUTES (ANGLE)	$2.909 \times 10^{-4}$	Radians	POUNDS/FOOT	1.488	Kgs./meter
			Pounds/inch	178.6	Grams/cm.
OUNCES	16	Drams	POUNDS/SQ. FOOT	0.01602	Feet of water
Ounces	137.5	Grains	Pounds/sq. foot	$4.883 \times 10^{-4}$	Kgs./sq. cm.
Ounces	0.0625	Pounds	Pounds/sq. foot	$6.945 \times 10^{-3}$	Pounds/sq. inch
Ounces	$28.349527$	Grams			
Ounces	0.9115	Ounces (troy)	POUNDS/SQ. INCH	0.06804	Atmospheres
Ounces	$2.790 \times 10^{-5}$	Tons (long)	Pounds/sq. inch	2.307	Feet of water
Ounces	$2.835 \times 10^{-5}$	Tons (metric)	Pounds/sq. inch	2.036	Inches of mercury
			Pounds/sq. inch	0.07031	Kgs./sq. cm.
OUNCES, TROY	480	Grains	QUARTS (DRY)	67.20	Cubic inches
Ounces, troy	20	Pennywghts. (troy)	QUARTS (LIQ.)	57.75	Cubic inches
Ounces, troy	0.08333	Pounds (troy)			
Ounces, troy	31.103481	Grams	QUINTAL, ARGENTINE	101.28	Pounds
Ounces, troy	1.09714	Ounces, avoird.	Quintal, Brazil	129.54	Pounds
			Quint., Castile, Peru	101.43	Pounds
OUNCES (FLUID)	1.805	Cubic inches	Quintal, Chile	101.41	Pounds
Ounces (fluid)	0.02957	Liters	Quintal, Mexico	101.47	Pounds
			Quintal, Metric	220.46	Pounds
OUNCES/SQ. INCH	0.0625	Lbs./sq. inch			
PARTS/MILLION	0.0584	Grains/U.S. gal.	1	8.0208	Overflow rate.
Parts/million	0.07016	Grains/Imp. gal.	Sq. FT./GAL./MIN.		(ft./hr.)
Parts/million	8.345	Lbs./million gal.			
PENNYWGHTS. (TROY)	24	Grains	TEMP. (°C.) + 273	1	Abs. temp. (°C.)
Pennywghts. (troy)	1.55517	Grams	Temp. (°C.) + 17.78	1.8	Temp. (°F.)
Pennywghts. (troy)	0.05	Ounces (troy)	Temp. (°F.) + 460	1	Abs. temp. (°F.)
Pennywghts. (troy)	$4.1667 \times 10^{-3}$	Pounds (troy)	Temp. (°F.) - 32	5/9	Temp. (°C.)
PINTS	0.4732	Liter			
POUNDS (AVOIR.)	16	Ounces	TONS (LONG)	1016	Kilograms
Pounds (avoird.)	256	Drams	Tons (long)	2240	Pounds
Pounds (avoird.)	7000	Grains	Tons (long)	1.12000	Tons (short)
Pounds (avoird.)	0.0005	Tons (short)			
Pounds (avoird.)	453.5924	Grams	TONS (METRIC)	$10^{-3}$	Kilograms
Pounds (avoird.)	1.21528	Pounds (troy)	Tons (metric)	2205	Pounds
Pounds (avoird.)	14.5833	Ounces (troy)			
Pounds (avoird.)	0.454	Kilograms	TONS (SHORT)	2000	Pounds
			Tons (short)	32000	Ounces
POUNDS (TROY)	5760	Grains	Tons (short)	907.18486	Kilograms
Pounds (troy)	240	Pennywghts. (troy)	Tons (short)	2430.56	Pounds (troy)
Pounds (troy)	12	Ounces (troy)	Tons (short)	0.89287	Tons (long)
Pounds (troy)	373.24177	Grams	Tons (short)	29166.66	Ounces (troy)
Pounds (troy)	0.822857	Pounds (avoird.)	Tons (short)	0.90718	Tons (metric)
Pounds (troy)	13.1657	Ounces (avoird.)			
Pounds (troy)	$3.6735 \times 10^{-4}$	Tons (long)	TONS OF WATER/24 HRS.	83.333	Pounds water/hr.
Pounds (troy)	$4.1143 \times 10^{-4}$	Tons (short)	Tons of water/24 hrs.	0.16643	Gallons/min.
Pounds (troy)	$3.7324 \times 10^{-4}$	Tons (metric)	Tons of water/24 hrs.	1.3349	Cu. ft./hr.
POUNDS OF WATER	0.01602	Cubic feet	WATTS	0.05692	B. T. Units/min.
Pounds of water	27.68	Cubic inches	Watts	44.26	Foot-pounds/min.
Pounds of water	0.1198	Gallons	Watts	0.7376	Foot-pounds/sec.
Pounds of water	0.10	Imp. gallon	Watts	$1.341 \times 10^{-4}$	Horse-power
			Watts	0.01434	Kg.-calories/min.
			Watts	$10^{-3}$	Kilowatts
LBS. OF WATER/MIN.	$2.670 \times 10^{-4}$	Cubic ft./sec.			
POUNDS/CUBIC FOOT	0.01602	Grams/cubic cm.	WATT-HOURS	3.415	Br. Thermal Units
Pounds/cubic foot	16.02	Kgs./cubic meter	Watt-hours	2655	Foot-pounds
Pounds/cubic foot	$5.787 \times 10^{-4}$	Lbs./cubic inch	Watt-hours	$1.341 \times 10^{-3}$	Horse-power hrs.
			Watt-hours	0.8605	Kilogram-calories
			Watt-hours	367.1	Kilogram-meters
			Watt-hours	$10^{-3}$	Kilowatt-hours

## SEWAGE CHARACTERISTICS

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### INTRODUCTION

The development of communities as centers of concentration of population has created numerous social problems not the least of which are the provision of a safe water and the adequate disposal of wastes. In the 19th Century several large European cities initiated the use of closed conduits or pipes for the collection of human wastes when it became apparent that the use of the streets as open sewers was creating increasingly intolerable living conditions. Although the sewage was removed from the doorstep, its discharge to nearby rivers and streams produced obnoxious odours and unsightly conditions in highly desirable recreational areas.

At the same time diseases of epidemic proportion were traced to water supplies originating from these same rivers and streams. Tiny organisms called bacteria were discovered in sewage, some of which were found to be responsible for such diseases as typhoid fever, paratyphoid fever, dysentery and cholera. A two-fold solution to the problem thus became apparent, involving both sewage and water treatment.

A more intensive study of bacterial types has disclosed that only a small number of them are responsible for disease. These and other bacteria are destroyed in nature through the activities of higher forms of microbial life. Together the organisms play a major role in degrading or breaking down organic matter (dead plants and animals and their wastes). Through the harnessing of these organisms, under optimum conditions such as are provided in a sewage treatment plant, the degradation of organic wastes can be speeded up and controlled.

### SOURCES OF SEWAGE

In nature sewage is present as the waste product of human and animal life. Man, through his resourcefulness, has added to this the waste products of industrial and commercial activity. Thus sewage has become complex in its composition varying widely in both volume and concentration.

Domestic wastes are those that originate in the household from the bathroom, the kitchen and the laundry-room. These can be readily treated in a properly designed sewage treatment plant. Industrial and commercial waste products may also be acceptable for treatment in a municipal sewage plant. However, in some instances, it may be necessary to treat them separately due to their complex nature.

### QUANTITY OF SEWAGE

In addition to carrying domestic and industrial wastes the sanitary sewers may receive large quantities of water from rain and street washings. Water in the ground may also enter sewers through broken pipes, poorly constructed sewer lines and illegal storm sewer connections. Older sewer systems may combine the collection of sanitary sewage and storm water in a single sewer, however, present practice requires the separate collection of each. This is understandable when it is realized that a treatment plant must be designed on the basis of the total flows reaching it. Thus it becomes very uneconomical to construct a large plant for the purpose of treating immense quantities of very dilute sewage.

The total quantity of sewage reaching the plant is called the hydraulic load and this will vary from hour to hour and differ from day to day. Normally flows will range between 70 and 130 per cent of the water consumption. The percentage will be increased if infiltration is a factor while it will be lowered due to lawn watering, car washing, hydrant flushing and many other domestic and industrial uses for which the water is not directed to the sanitary sewer system. An average municipality without large industrial sewage contributors may generate



approximately 100 gallons of sewage per person per day. It is interesting to note that solids account for less than 0.1 of 1 per cent of weight of the total sewage flow. The remaining 99.9 per cent is water which provides a means of carrying the solids through the sewer pipes.

### SEWAGE CHARACTERISTICS

A treatment plant removes contaminants from sewage making it acceptable for discharge to lakes or streams. In so doing, the physical, chemical and bacteriological characteristics of the sewage are changed. These changes can best be seen by comparing the characteristics of the raw sewage, primary effluent and final effluent of a treatment plant. Sketch No. 1 shows the raw sewage entering the plant with the primary effluent comprised of the liquid leaving the primary settling tank (clarifier). When the sewage undergoes biological treatment, or secondary treatment, the liquid discharge is called the plant or final effluent.

#### A. Physical Characteristics

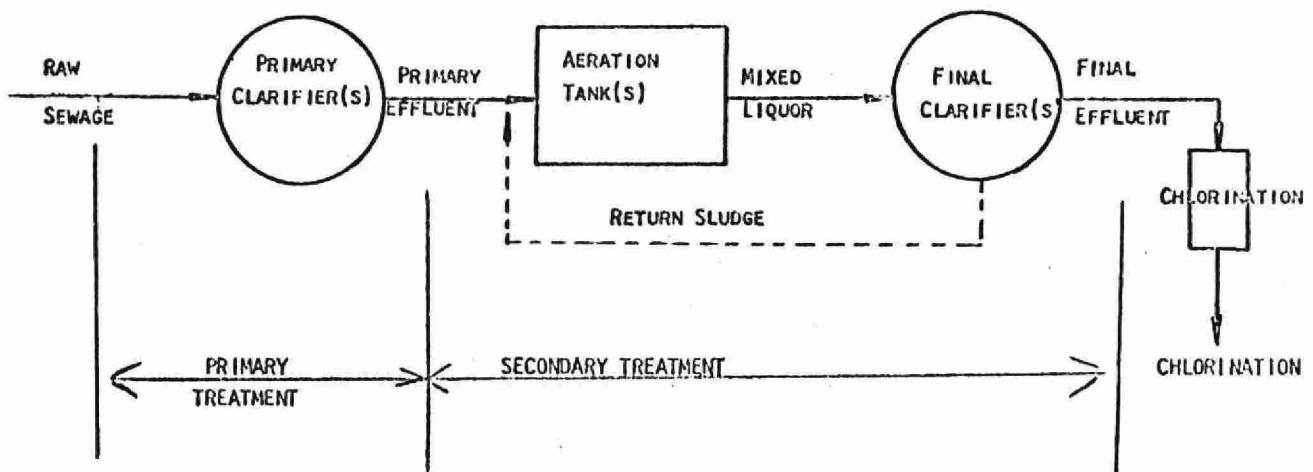
The physical characteristics of sewage are those which affect our senses and would include temperature, turbidity, colour and odour. Table No. 1 compares the physical changes which take place through a typical treatment plant.

TABLE NO. I

	Temperature	Turbidity	Colour	Odour
Raw Sewage	Varies	high in solids	milky-grey to black	musty to sulphurous
Primary Effluent	lower temperature	fine non-settleable solids	greyish to colourless	musty to sulphurous
Final Effluent	lower temperature	no visible solids	clear colourless	fresh chlorinated

SKETCH NO. 1

TYPICAL SEWAGE TREATMENT PLANT



The temperature of raw sewage will vary depending upon the source of water supply for the municipality. However, the resultant raw sewage is always somewhat warmer. As the sewage passes through the treatment plant the temperature decreases. The higher the sewage temperature the more rapid the decomposition and the better the settleability.

Raw sewage is highly turbid, containing many different types of solids such as paper, rags, garbage, feces, sand and silt. Primary effluent will contain finely suspended and floating matter which can be removed through biological treatment, producing a clear, colourless final effluent.

The normal milky-grey colour of raw sewage will not be evident if coloured industrial wastes or partially decomposed sewage are involved. Septic or partially decomposed sewage is dark, sometimes black in colour with a sulphurous odour. Normal sewage smells musty but not unpleasant. Primary effluent will be similar to raw sewage except that a large portion of the solids have been removed. The final effluent of a properly operated secondary treatment plant will be clear and colourless with a fresh, often chlorinated odour.

#### B. Chemical Characteristics

Chemically, sewage is composed of a great many inorganic and organic solids which are carried in water. In addition the sewage may contain dissolved gases and living organisms. Inorganic or fixed substances are recognized by the fact that they are inert and generally not subject to decay or combustion. On the other hand, organic materials will decompose and are sometimes called volatile matter since they will burn when heated to high temperatures.

Inorganic and organic substances which can be seen in the sewage are known as suspended solids. These are the solids which can be removed from the sewage by physical or mechanical means, such as sedimentation or filtration. Those that cannot be readily seen are classified



as dissolved solids. A third group called colloidal solids can be loosely described as very fine particles which are nonsettleable. These may or may not be visible to the naked eye. For simplification the colloidal solids classification will be grouped partially as suspended solids and partially as dissolved solids. Total solids, as the name implies, includes all of the solids constituents of sewage.

Quantities or concentrations of solids, whether inorganic or organic will differ from hour to hour and from sewage plant to sewage plant. Average concentrations of solids in a medium strength sewage are shown graphically in Sketch No. 2. The amounts of suspended solids and organic material present in the sewage indicate the strength of the sewage. The successful operation of a treatment plant depends, to a great extent, upon this sewage strength.

#### Inorganic Solids

This material consists of sand, silt, clay, the dissolved minerals and salts in community water supplies and any other inert matter contained in wastes discharged to the sewers. Thus a hard water will produce a high mineral content in the sewage. Some of the more common minerals and salts found in sewage are sulphates, carbonates, bicarbonates and chlorides of calcium, magnesium, sodium, potassium and iron. In an average domestic sewage these are not normally troublesome to a sewage treatment process.

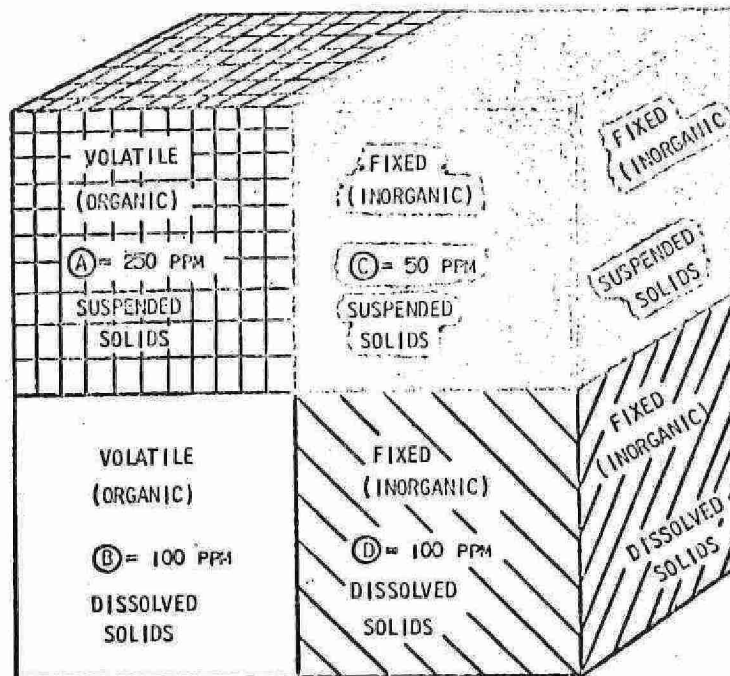
#### Organic Solids

Organic solids are generally of animal or vegetable origin including the waste products of animal and vegetable life. Some synthetic compounds, however, are also organic in nature. All organic matter consists of hydrogen, oxygen and carbon. These substances may be combined with inorganic nitrogen, sulphur or phosphorous. The principal groups formed are called proteins, carbohydrates and fats. These serve as food for bacteria and higher forms of organisms resulting in decomposition or decay of the organic matter. Decomposition leads to the formation of carbon dioxide, nitrogenous compounds consisting of ammonia, nitrites and nitrates, and sulphurous

SKETCH NO. 2

COMPOSITION OF SOLIDS IN A MEDIUM

STRENGTH RAW SEWAGE



$$\text{TOTAL SOLIDS} = \text{A} + \text{B} + \text{C} + \text{D} = 250 + 100 + 50 + 100 = 500 \text{ PPM}$$

$$\text{TOTAL VOLATILE SOLIDS} = \text{A} + \text{B} = 250 + 100 = 350 \text{ PPM}$$

$$\text{TOTAL FIXED SOLIDS} = \text{C} + \text{D} = 50 + 100 = 150 \text{ PPM}$$

$$\text{TOTAL SUSPENDED SOLIDS} = \text{A} + \text{C} = 250 + 50 = 300 \text{ PPM}$$

$$\text{TOTAL DISSOLVED SOLIDS} = \text{B} + \text{D} = 100 + 100 = 200 \text{ PPM}$$

substances comprised of sulphates as well as hydrogen sulphide gas. These waste products are in turn utilized by plant and animal life in their growth processes. The cycles of life, death and decay involving carbon, nitrogen and sulphur are shown in Sketches No. 3, 4 and 5 respectively.

The organic strength of sewage is principally a measure of its capacity to undergo decomposition. The standard criteria for determining the organic strength of sewage is called the Biochemical Oxygen Demand or BOD. The BOD is simply a measure of the oxygen utilized in decomposing organic matter to a stable condition. Normally the test is carried out at a temperature of 20°C over a period of five days with the result being reported in ppm. 5-day BOD (BOD<sub>5</sub>).

Domestic raw sewage will normally have a BOD<sub>5</sub> ranging between 100 ppm and 300 ppm. Industrial wastes could significantly change this however. During primary treatment the BOD<sub>5</sub> generally drops by 30 to 40 per cent, with full secondary treatment reducing the BOD<sub>5</sub> by approximately 95 per cent. The final effluent in a well operated plant should not contain more than 15 ppm BOD<sub>5</sub>.

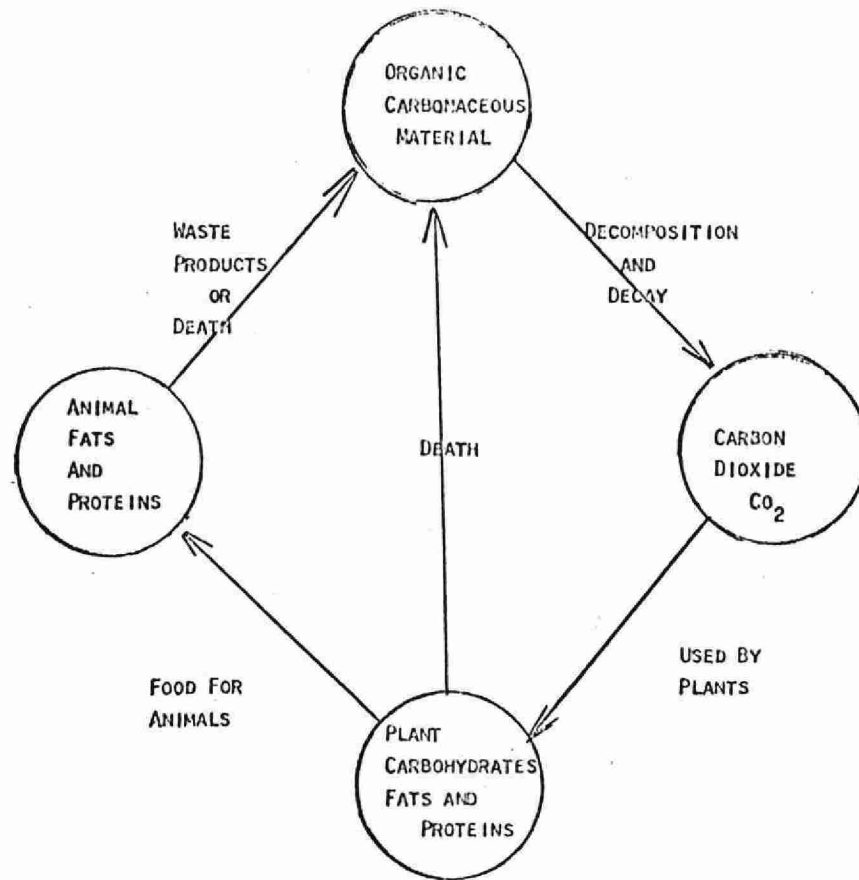
#### Dissolved Gases

Sewage contains small and varying concentrations of dissolved gases. Among the most important of these is oxygen, present in the original water supply and also dissolved from air in contact with the surface of flowing sewage. In addition to dissolved oxygen, sewage may contain other gases such as carbon dioxide, ammonia and hydrogen sulphide, the products of decomposition, as well as nitrogen dissolved from the atmosphere. These gases although small in amount, may serve as indicators of the degree of decomposition of sewage.

#### Solids

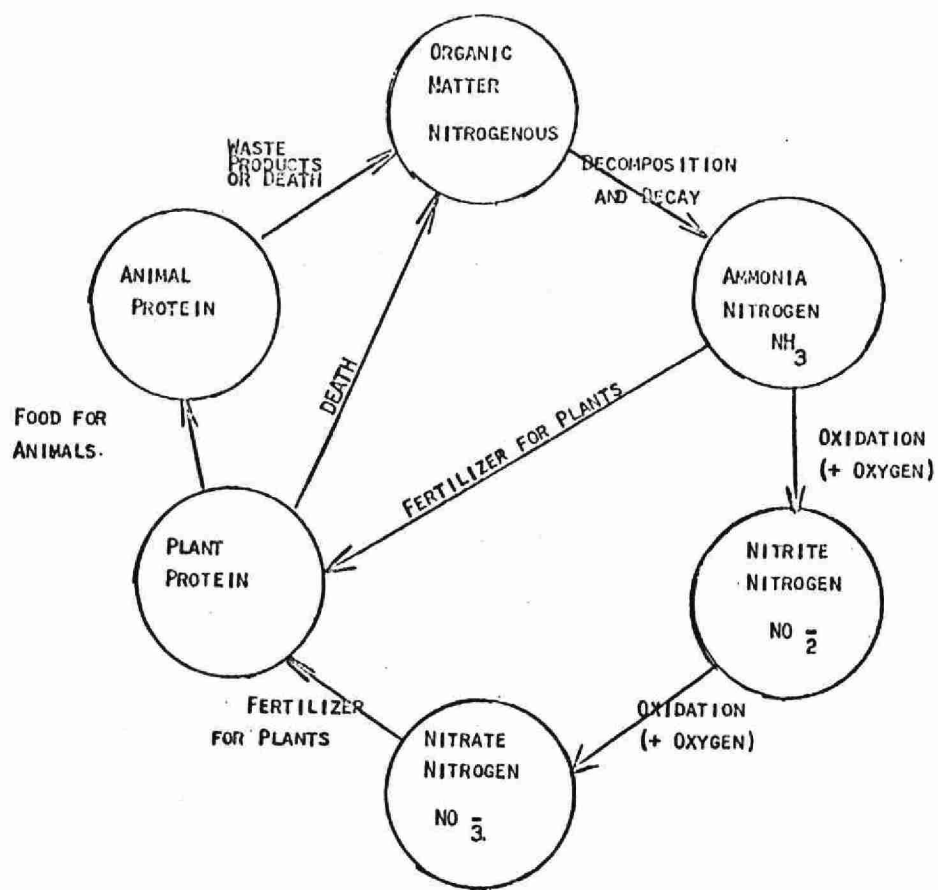
The total solids in a sewage are the combination of all inorganic and organic solids or the total of the suspended and dissolved solids. From Sketch No. 2 it can be seen that the concentration of total solids in an average medium strength sewage is given as 500 ppm. This consists

SKETCH NO. 3

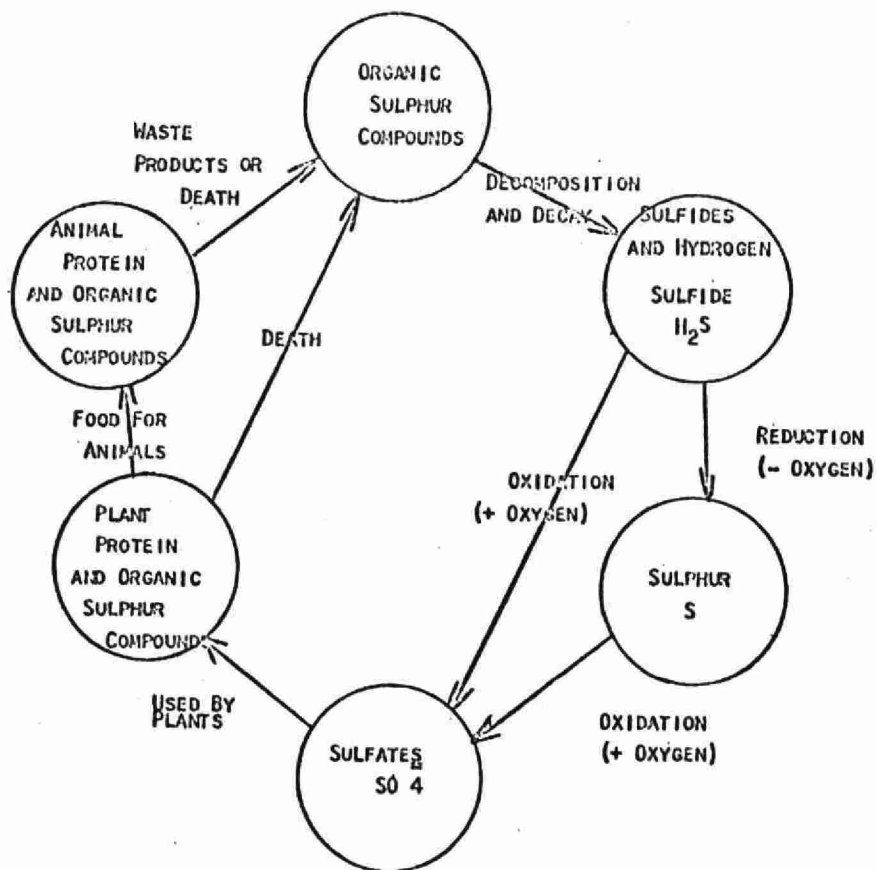


CARBON CYCLE

SKETCH NO. 4



NITROGEN CYCLE

SKETCH NO. 5SULPHUR CYCLE

of 350 ppm organic matter in addition to 150 ppm inorganic matter. The same total solids figure is arrived at by adding the suspended and dissolved solids which are shown as 300 ppm and 200 ppm respectively. The figures presented are only for purposes of example and should not be considered optimum or necessary in any particular municipality.

The addition of storm or ground water into the sewage may change these solids relationships significantly. Similarly the introduction of industrial wastes may increase the solids content, particularly the organic solids, with very definite variations in the strength of the sewage. Also, sewage varies widely in both composition and volume from hour to hour depending upon changes in community activities. Sewage is likely to be at its maximum strength and flow during the day-time and at a minimum during the night hours. On weekends and holidays flows and strength are frequently reduced due to the lowered rate of communal activity. Therefore no data on sewage can be applied equally to all sewages at all times.

A primary treatment plant will normally reduce suspended solids by 40 to 60 per cent. Complete secondary treatment generally will remove 90 to 95 per cent of the suspended solids producing a final effluent with suspended solids less than 15 ppm.

### Nutrients

Nitrogen and phosphorus are the two nutrients which are of greatest concern in the operation of a sewage treatment plant. It has been generally concluded that a nitrogen-to-BOD ratio of 1-to-20 and a phosphorus-to-BOD ratio of 1-to-100 by weight is essential for optimum growth of organisms involved in the decomposition of organic matter. Domestic sewage normally contains an excess of both nitrogen and phosphorus. This excess, when discharged in the plant effluent acts as a fertilizer in promoting the growth of algae in receiving waters.

Total nitrogen is present in organic wastes in the form of ammonia nitrogen, organic nitrogen, nitrite nitrogen and nitrate nitrogen each representing a different stage of waste stabilization. Table No. 2 summarizes the ranges of

typical nitrogen analyses for a conventional sewage treatment plant.

TABLE 2

Nitrogen Concentrations

	Ammonia Nitrogen (ppm)	Organic Nitrogen (ppm)	Nitrite Nitrogen (ppm)	Nitrate Nitrogen (ppm)
Raw Sewage	15-50	25-85	less than 0.1	less than 0.5
Primary Effluent	15-50	25-85	less than 0.1	less than 0.5
Final Effluent	0-1	5-20	less than 5.0	greater than 10

While nitrogen may change form during decomposition, the total nitrogen loss through a conventional secondary treatment plant is generally very low. Sewage oxidation ponds or lagoons have, however, been found to be successful in the removal of nutrients. Ammonia nitrogen was reportedly reduced from 75 to 90 per cent with organic nitrogen reduced by 60 per cent and phosphorus reduced by 96 per cent.

C. Bacteriological Characteristics

Sewage contains countless numbers of living organisms most of them too small in size to be visible except with the use of a microscope. They are a natural living part of the organic matter found in sewage and they are important because they are one of the reasons for the success of our present treatment processes. The microscopic living organisms in sewage may generally be considered to consist of bacteria and other more complex higher forms of organisms.

Fresh raw sewage may normally contain from 10 to 200 million bacteria per 100 millilitres. These bacteria may either be harmful or non-harmful to humans. Complete secondary treatment may be expected to reduce these numbers by from 80 to 95 per cent with effluent chlorination increasing the per cent "kill" to 99.9 per cent or better. The highest



reductions are generally only attained when the treatment plant is operating efficiently.

## SEWAGE PLANT PROCESSES

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### INTRODUCTION

This introductory lecture is intended to provide a basic outline of the sewage treatment processes presently available. Although reference is made to the purposes and applications of the various processes, design details are not dealt with since these will be reviewed in greater detail during the remainder of this course and the two courses which will follow in the future. No attempt is made to cover the treatment of chemical industrial wastes but the processes that are described are applicable to organic industrial wastes.

### NATURE OF SEWAGE

Municipal sanitary sewage normally contains 99.5% water with the remaining 0.5% consisting of solids suspended or dissolved in the water. These solids may be described as follows:

1. Grit - heavy material such as sand or gravel, inorganic.
2. Settleable solids - solid material, organic or inorganic, which will settle out when low flow conditions are present.
3. Floating solids - solid material which will float when subjected to low flow conditions such as grease and scum.
4. Fine colloidal material - very small particles of solid material which is not readily removed by adjustment in the rate of flow.
5. Dissolved substances - solids in solution, i.e., sugar in water.

The processes which will be described provide for the removal of the above material at varying rates of efficiency together with an associated removal of biochemical oxygen demand.

Since sewage from different municipalities will differ in the chemical characteristics, the actual type of sewage treatment adopted will depend on the characteristics of the sewage and the size of the municipality.

### OBJECTIVES OF SEWAGE TREATMENT

The objectives of sewage treatment will vary according to the location of the treatment facility and the method of disposal.

There are three different methods of sewage disposal which may be utilized as follows:

1. On the surface of the land. The sewage raw or partially treated can be sprayed onto land for final disposal. Also broad irrigation using the ridge and furrow method may sometimes be utilized.
2. Sub-surface disposal areas employ weeping tiles or seepage pits for final disposal of the sewage. Here again the sewage requires generally only partial treatment, i.e., coarse solids removal, dependent of course upon the soil characteristics of the tile bed area.
3. Discharge to surface waters where generally a very high degree of treatment is required since this method relies on the dilution provided by the receiving water.

This latter procedure is the most common used for final disposal of the treated sewage at municipal sewage treatment plants.

Therefore, sewage treatment plants employ processes for the removal of coarse material, separation of the fine particles of solids from the water (clarification), stabilization of sewage for the removal of the organics which create

a biochemical oxygen demand and the destruction of harmful bacteria or other organisms.

## SEWAGE TREATMENT PROCESSES

### General

As noted previously, the processes to be described will be the types which are commonly used for municipal sewage treatment. Also since the common practice is to discharge the final effluent into a water way, the processes which do not have the discharges to the watercourse are not discussed in this paper. The number of this latter type of plants in the province is very limited and generally all have been provided with percolation ponds to which the treated sewage is discharged for final seepage into the ground. It should be noted that in instances where higher degrees of treatment are required for the protection of the receiving water, the capital, operational and maintenance costs of the treatment plant increase accordingly.

### Primary Treatment

Primary treatment is a term applied to processes where grit, screenings, and settleable material are removed by physical methods. The processes involved are:

1. Grit removal - tanks are provided where the raw sewage is passed through the tank at a design velocity of approximately one foot per second for the removal of the grit. The grit is then disposed of on land or in sanitary land fill.
2. Screening - coarse or fine screens are provided which can be manually or mechanically cleaned for the removal of large floating objects in the sewage. These objects will include pieces of wood, paper, etc. Here the material is removed from the raw sewage for disposal generally in a sanitary land fill.
3. Comminution - grinders, cutters, or shredders where the large particles are ground up so that the size is reduced and the particles are then returned to the raw sewage.

Normally a treatment plant is provided with screening or comminution equipment to handle the large solids. In instances where both pieces of equipment are provided, the screening is normally used as a "back-up" for the comminution equipment.

4. Primary sedimentation - includes septic tanks, two storey tanks with separate sludge compartments, plain sedimentation with mechanical sludge removal, primary clarifiers with mechanical sludge removal. The latter two types of tanks with the mechanical sludge removal equipment are normally used in municipal sewage treatment plants with the former two being considered as relics of the past.

Generally primary sewage treatment units are designed for the removal of up to 60 per cent of the suspended solids with an associated reduction in the biochemical oxygen demand of between 30 and 35 per cent. The primary sewage treatment process is normally used to provide an initial degree of treatment prior to discharging the sewage to a secondary treatment plant or is in some cases all the treatment that is provided where the effluent is discharged to a large waterway with a very high dilution factor. The sewage is normally disinfected prior to discharge to a watercourse.

### Secondary Treatment

Secondary treatment is the term applied to biological processes providing a higher degree of efficiency than primary treatment. Organisms essential to the process require oxygen and there are no odours, providing aerobic conditions are maintained. The following types of processes are considered as secondary treatment:

1. Activated sludge - the conventional activated sludge plant consists of aeration tanks sized to provide approximately six hours retention based on the average raw sewage flow to the plant with final settling tanks provided for the separation of the biological floc which is grown in the aeration tank from the water. The final effluent is discharged from the top of the tank as the clear liquid with the biological floc is pumped from the bottom of the tank to the inlet of the aeration tanks. A portion of this biological floc, or activated sludge,

is wasted to the primary settling tank. The primary settling tank performs a similar function from which the sludge is pumped off the bottom for further treatment and disposal. Numerous variations of the conventional activated sludge process have been developed and are briefly outlined as follows:

(a) Extended aeration activated sludge - the plant is preceded by only grit and screening removal facilities. The raw sewage is discharged without primary treatment to the aeration tanks which in turn provide a retention time of approximately 24 hours. The effluent from the aeration tanks is discharged to the final settling tanks for separation of the activated sludge and the water. The activated sludge is returned to the inlet of the aeration tanks. Normally sludge holding tanks are provided to receive waste activated sludge which is not returned to the aeration tanks. The sludge holding tanks are periodically pumped into trucks for final disposal.

(b) Step aeration - this plant is very similar to the conventional activated sludge plant with the exception that the sewage from the primary settling tank is discharged to the aeration tanks not only at the inlet end but periodically along the length of the tank. The attempt here is to reduce the effect of shock loading on the aeration section.

(c) Contact stabilization - grit and screening facilities are provided only for primary treatment with the raw sewage being discharged to a very small aeration tank normally with a retention time of approximately 60 to 90 minutes from which the sewage is directed to final settling tanks. The recirculated activated sludge from the final settling tank is discharged to a re-aeration tank which has a relatively long retention time. The effluent from the re-aeration tank is returned to the contact tank to complete the process. Waste activated sludge is normally discharged from the re-aeration tank to an aerobic digestion tank or some other form of sludge treatment.

(d) High rate - this is a relatively new development in the sewage treatment plant process where extremely high rates of primary effluent are applied to the aeration tanks which are

of course, followed by the final settling tanks with recirculated activated sludge rates in excess of 100 per cent. The attempt with this type of treatment is to provide the same degree of treatment using less tankage.

Plants of this type with primary settling tanks normally utilize heated, anaerobic sludge digestion as the method of sludge treatment. Plants not equipped with primary settling facilities are usually provided with aerobic digesters for sludge treatment.

In all of the above processes a very high degree of treatment is achieved with final effluent biochemical oxygen demands between 15 parts per million and 25 parts per million. The larger plants in the Province are generally of the conventional activated sludge type with the modifications being utilized normally in the small communities.

2. Oxidation ditch - this method of treatment involves the construction of a ditch in the shape of a race track to which the sewage is discharged for aeration followed by final settling facilities. The design criteria of this type of plant is similar to that of an extended aeration tank. The main feature is the method of aeration. The plants referred to in item number 1 above normally all use diffused aeration or mechanical aeration of the type where a vertical shafted propeller is suspended in the liquid to provide the aeration. With the oxidation ditch a "brush" rotor is utilized which is essentially the same as a paddle wheel to propel the sewage around the ditch and provide the necessary aeration.

3. Waste stabilization ponds - waste stabilization ponds or lagoons have been utilized for the treatment of sewage where land is available. The conventional pond is designed with a maximum water depth of five feet and a retention time of approximately 120 days. Aerated ponds have been constructed with aeration times of one day to five days. As yet the efficiency from these lagoons is not comparable to the types of processes outlined in items number 1 and 2. However, the conventional lagoon can be constructed for discharge to a waterway which does not have a sufficient flow in the summer to receive the effluent from a mechanical sewage treatment



plant. The lagoon can be used to store the sewage during the critical summer months for discharge during the fall. A lagoon of the conventional type is normally designed on the basis of a requirement of 100 persons per acre or 20 pounds of biochemical oxygen demand per acre per day. On occasion, the lagoons have been designed to provide six months storage where the characteristics of the receiving stream or its use for recreational purposes is critical.

A conventional lagoon, due to its size, utilizes the processes of nature for the reduction of the organic content in raw sewage. There is no sludge build-up in the bottom of a conventional lagoon and consequently the operation and maintenance of the lagoon is restricted to careful control of the liquid level structures and cutting of grass.

4. Trickling filters - trickling filter plants have been used in the past to provide secondary treatment. However, these plants are adversely affected by the climatic conditions in Ontario and, therefore, have not provided generally the treatment efficiency required of secondary treatment plants. As a result, a number of plants in the Province have been converted to activated sludge plants.

The manufacturers have produced "package" plants particularly of the modified activated sludge process which can be purchased as opposed to a custom built plant. Normally these package plants are smaller in size ranging upwards to one million gallons per day.

#### Sludge Treatment

The sewage solids removed by the processes described are generally treated to reduce the volume and to stabilize the sludge. The term stabilization is used to mean the changing of the state of the sludge so that it is in a form which can be readily handled and dried without creating odour problems or other nuisances. A large variety of processes are available for the treatment of sludge and the basic types are outlined as follows:

1. Anaerobic heated sludge digestion in which the sludge is



discharged to closed tanks which are heated to approximately 95 degrees F. A biological process reduces the water content of the sludge and provides a product which can be filtered to further reduce the volume of sludge to be handled by trucking.

2. Vacuum filtration - this method may be followed for the treatment of raw sludge from a primary settling tank or for further concentration of the digested sludge from heated digesters.

3. Sand beds - the sludge from the heated digester can be discharged to sand beds to drain the water out of the sludge for return to the plant.

4. Incineration or drying - the digested or filtered sludge can be placed into an incinerator for burning or drying, depending on the ultimate method of disposal. Generally, with incineration plants both heated digesters and vacuum filtration are provided.

5. Aerobic digestion - it is noted that some of the processes for secondary treatment utilize aerobic digestion as a method of handling the waste sludge. Normally the concentrated sludge is trucked for land disposal.

6. Centrifuging - some work has been carried out on the use of large centrifuges for the separation of the sludge solids from the water. To date mechanical difficulties have generally restricted the use of this method of sludge treatment.

It must be recognized that the raw sludge collected from a primary settling tank normally has a moisture content of approximately 98 per cent, i.e., 100 gallons of sludge contains two gallons of solid material mixed in 98 gallons of water.

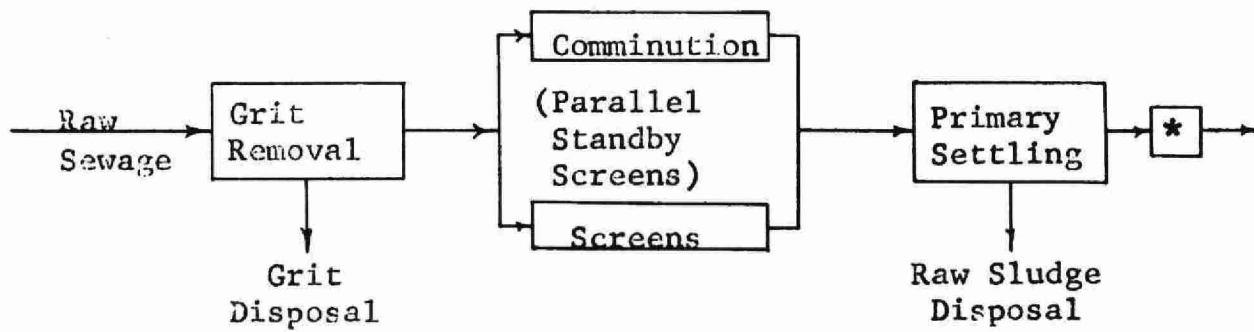
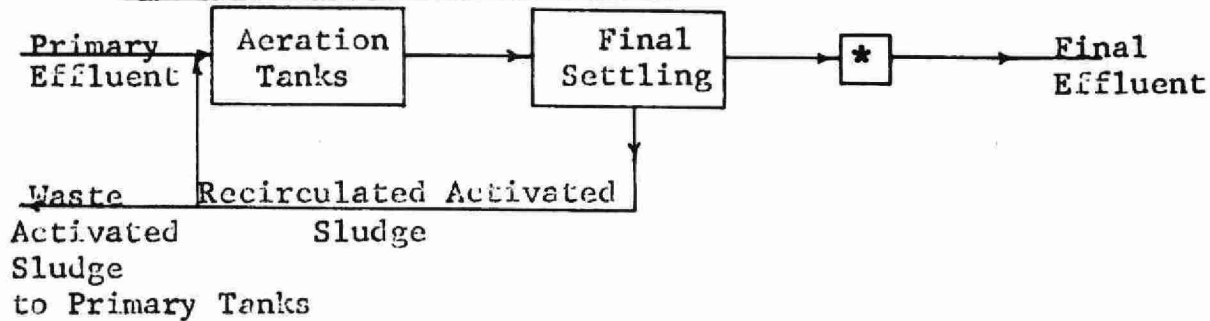
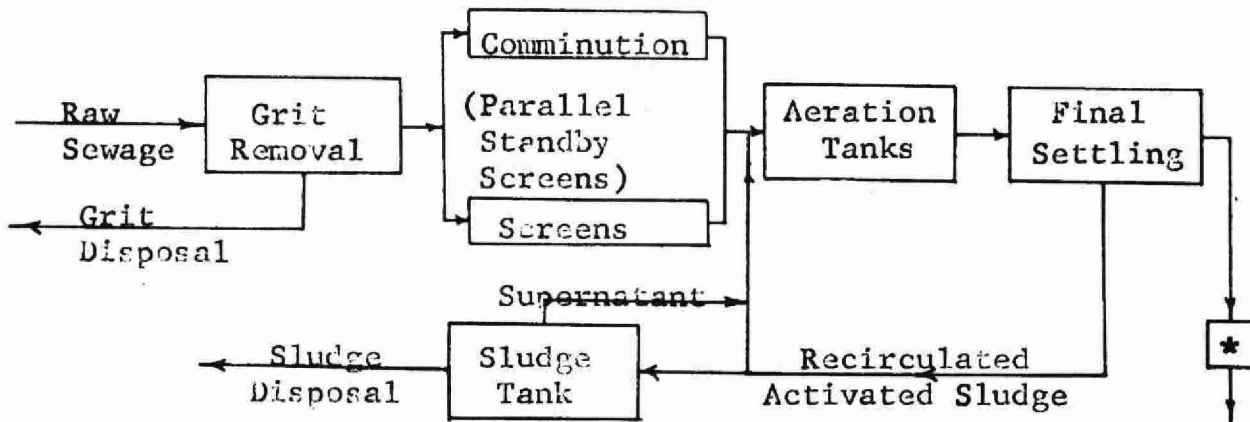
Final disposal is generally on the land and in some cases, sludge lagoons have been used. Difficulties with odours depend on the degree of stabilization provided by the treatment prior to final disposal.

### Effluent Polishing and Tertiary Treatment

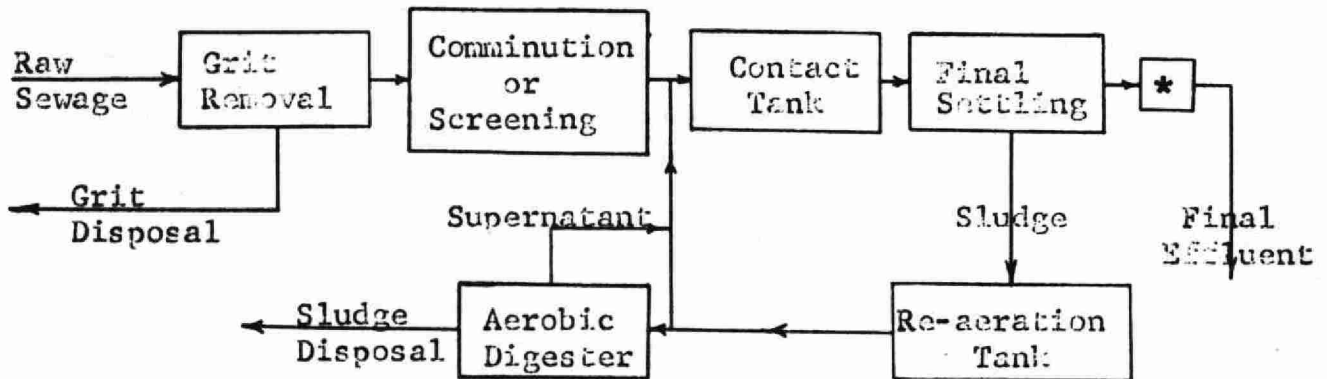
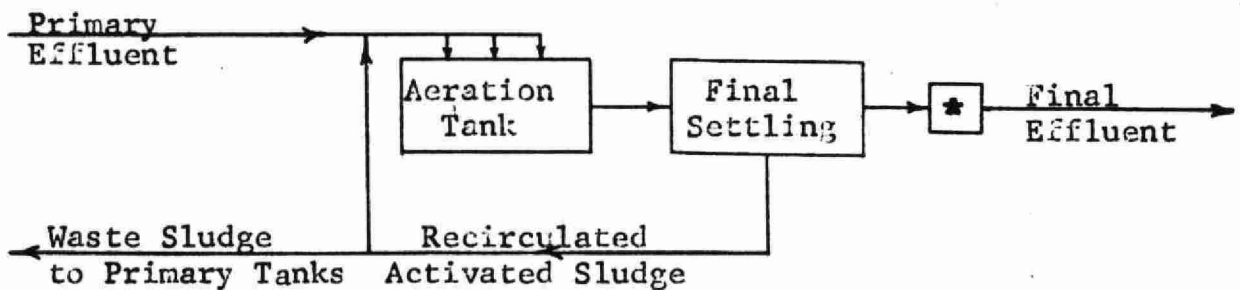
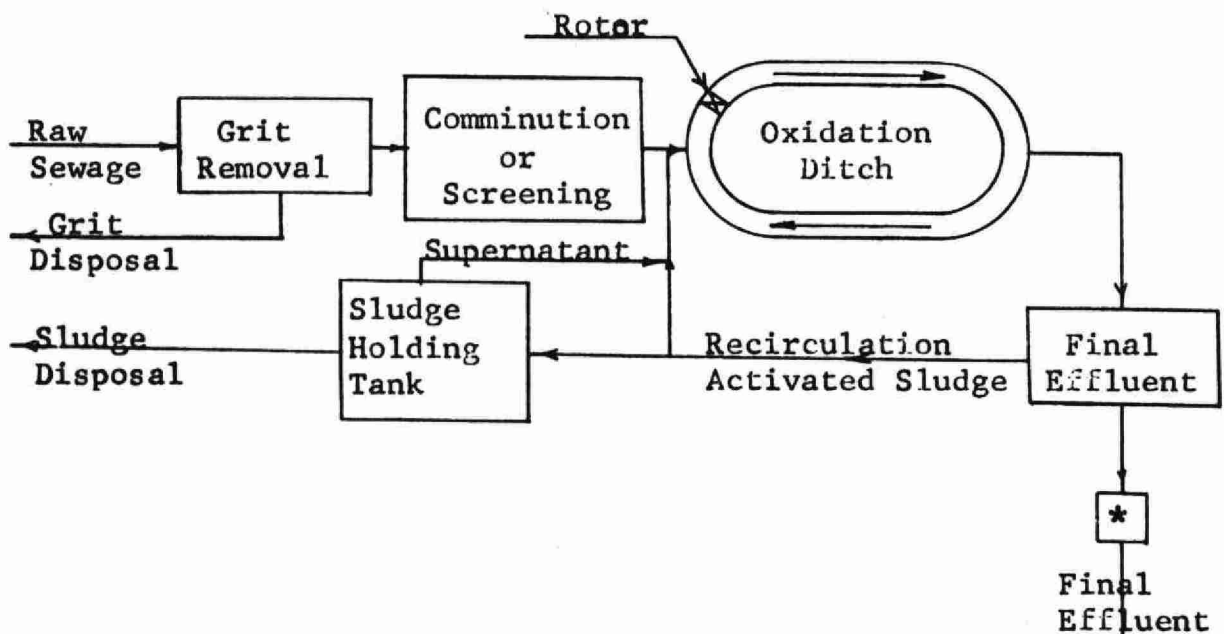
Effluent polishing and tertiary treatment are provided in cases where the degree of treatment provided at a secondary sewage treatment plant is not adequate for discharge of the effluent to the receiving water. Effluent polishing is defined as the removal of suspended matter and biochemical oxygen demand. Tertiary treatment is defined as the removal of nutrients such as nitrogen and phosphorus. Numerous effluent polishing systems have been constructed including the use of waste stabilization ponds after a secondary treatment plant, sand filters and high rate mechanical filters. Tertiary treatment can sometimes be effected by the use of lime injected into the supernatant return from the digester to the plant. This will remove a percentage of phosphorus which would ultimately be discharged in the sewage treatment plant effluent. Some research work has been undertaken for the removal of nitrogen through the use of controlled aeration in the plant itself and aeration towers for the final effluent. However, to date both forms of tertiary treatment are still in the development stage and have not been widely accepted primarily due to cost.

### Disinfection

Disinfection is commonly accomplished by effluent chlorination. Where chlorination facilities are installed in a treatment plant, provision is generally made for chlorine application at other points to assist in odour control and treatment adjustments. The prime purpose of disinfection however is to kill the bacteria and other small organisms which are harmful to human beings.

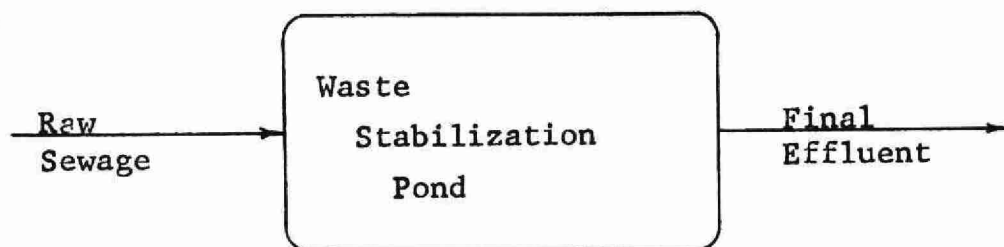
PRIMARY TREATMENTSECONDARY TREATMENTConventional Activated SludgeExtended Aeration

\* Chlorination if Effluent Discharged to Receiving Water.

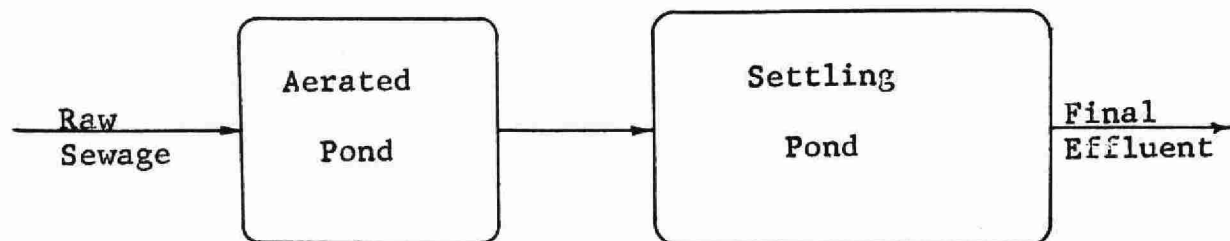
Contact StabilizationStep AerationOxidation Ditch

\* Chlorination if Effluent Discharged to Receiving Water.

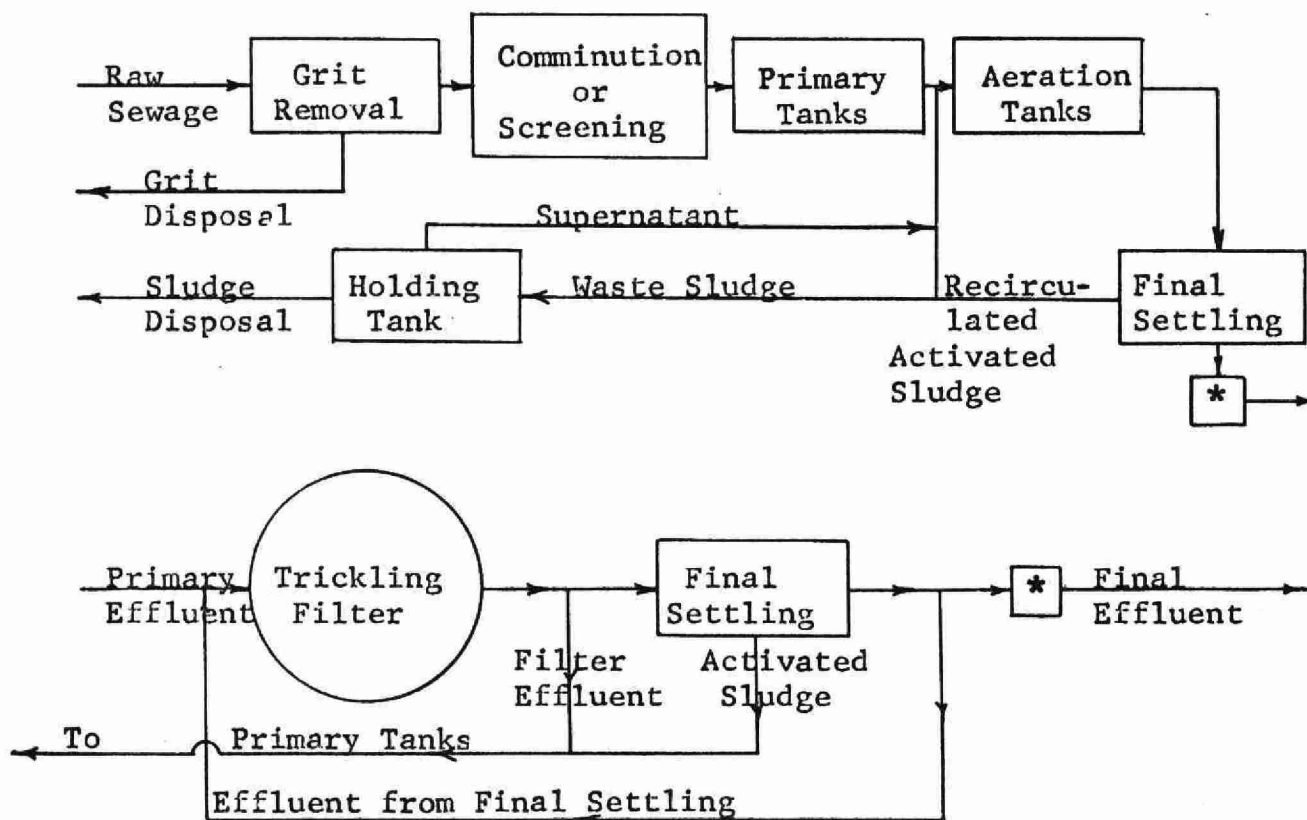
WASTE STABILIZATION PONDS  
Conventional Ponds



Aerated Ponds



High Rate



\* Chlorination if Effluent Discharged to Receiving Water.

THE EFFECTS OF SANITARY WASTES ON LIFE  
IN RECEIVING WATERS

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INTRODUCTION

The purpose of this talk is threefold; to illustrate briefly what life is like in natural waters, to describe what changes to the animals and plants occur where sanitary wastes are discharged, and to indicate how sewage plant operators can reduce the harmful effects of sanitary wastes to aquatic life.

BIOLOGY OF LAKES AND STREAMS

Let us begin by noting three generalizations about life in unpolluted water.

Firstly, all the living organisms in a stream or lake form a balanced system which is often referred to as a network of food chains. Each link in each chain depends on the previous link for its food. The big animals eat little animals which eat plants which make their own food from sunlight and nutrients dissolved in the water.

One simple food chain starts with the tiny one-celled plant Chlorella, which is eaten by the water flea, Daphnia. Daphnia may be eaten by minnows, which may be eaten by trout, which may be eaten by Man (if he is lucky enough to catch the trout). In this particular case, Man stands at the head of a food chain containing five members (Figure 1).

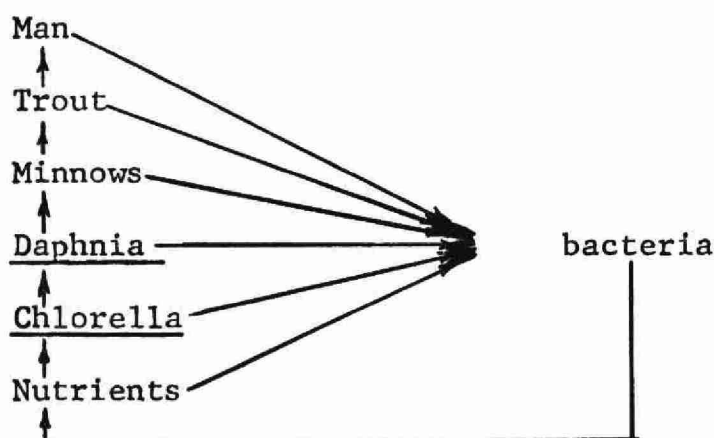


Figure 1. A simple food chain

The matter of course does not end here. All the dead plants and animals, and all their waste products, are broken down by bacteria to form nutrients again, and so the cycle is repeated.

The second generalization concerns numbers. If the biological system just described remains balanced, no single group of animals or plants may become excessively numerous, otherwise, the dominant group would quickly run out of food and starve, until the balance was restored.

Thirdly, water supports an immense variety of animals and plants. Every available kind of place is occupied by one or more creatures that are adapted to live there. Let us now look at a few selected organisms, starting with the plants.

### ALGAE IN RECEIVING STREAMS

The algae are simple plants without true roots, stems, leaves or flowers. One of the smallest has already been mentioned - Chlorella. It is a minute, drifting, spherical plant that when magnified a hundred times is no bigger than a pin-head! Cladophora is a large alga that can be seen with the naked eye. It grows in long strands attached to rocks and so live in fast-flowing rivers and along exposed shores. It has become a nuisance along the coast line of Lake

Ontario because it grows abundantly and smells foul when it dies.

Among aquatic flowering plants we will only mention two, the water lily and the duckweed. The water lily is one of the largest aquatic plants and may be rooted in water twenty feet deep. The little floating duckweed in contrast is less than a quarter of an inch across and is the smallest flowering plant known to Science.

#### ANIMAL LIFE IN RECEIVING STREAMS

Animals are equally varied. Paramecium is microscopic and feeds on bacteria. Mosquito larvae breathe air and are usually seen hanging by their breathing tubes from the surface film of stagnant water. Blackfly larvae, on the other hand, are anchored to rocks in fast-flowing streams and absorb oxygen dissolved in the water. Crayfish are scavengers that clamber about on the bottom of lakes and rivers. The only animals that can move around freely are the fish, and even they tend to specialize by living in water of a certain depth or a preferred temperature.

Finally, bacteria may be found everywhere, some breathing oxygen, some doing without, some causing disease in animals, others breaking down dead bodies, some able to turn the nitrogen of the air into nitrate fertilizer.

#### CHANGES DUE TO SANITARY WASTES

Let us now consider what happens to waters that receive sanitary wastes, noting as before our three general headings; the balance of Nature, the number of individuals of each kind, and the variety of living things represented.

As creatures most sensitive to sanitary wastes become eliminated, the balance of Nature is disturbed. Those organisms that can tolerate the new conditions thrive and multiply so that the observer is impressed by the prominence of a few groups over the rest. The immense variety of organisms normally present is suppressed and the total



number of species is reduced. We will now see how this comes about.

Firstly, if any organic matter is discharged into receiving waters, it is broken down by bacteria. The bacteria use up oxygen the same as do nearly all other living things. The more organic matter that is present, the more bacteria are produced and the more oxygen is consumed. The discharge of sanitary wastes, therefore, reduces the concentration of oxygen in the water. If less than 5 ppm of oxygen remain, trout are eliminated. Most fish require 3 ppm of oxygen. If the oxygen concentration periodically sinks below 1 ppm, then only those organisms survive that can breathe air directly - or can do without oxygen for a time. Under anaerobic conditions, when there is no dissolved oxygen at all, the balance of Nature is drastically upset, the variety of living things greatly reduced and the number of individuals of each kind vastly increased. Under the worst conditions, all organisms are suppressed except sewage fungi, a few hardy air-breathing animals, and those bacteria that do not need free oxygen. As the fungi look like dirty cotton wool and these particular bacteria give off the characteristic odour of septic sewage, most people consider anaerobic conditions undesirable.

#### DUTIES OF SEWAGE PLANT OPERATOR IN PROTECTING STREAM

To avoid this situation, the duty of the sewage plant operator is clearly to keep the biochemical oxygen demand of his plant effluent low. A BOD of 10 ppm is sufficient to remove all the dissolved oxygen from the water once over: a BOD of 20 ppm will remove it twice over. It is especially important to avoid releasing slugs of wastewater with a very high BOD - a little spread over a longer period does less damage. What can live in a lake or stream is determined by the worst conditions that occur - even if they happen only on one day a year. It is worth noting too that the concentration of dissolved oxygen in receiving waters is usually lowest at night so that an effluent with a high BOD would do less harm during daylight.

The second effect of sanitary wastes on receiving waters is caused by a deposit of sludge blanketing the lake or river bottom. This may suffocate or bury living things, changing a highly productive area into a desert. Fish which feed on bottom-living organisms will starve. In addition, the buried animals and plants will die and produce a BOD of their own, causing a further deterioration.

It is clearly desirable to keep the concentration of suspended solids consistently low in the sewage effluent, and to avoid the sudden discharge of effluents high in solids.

#### OTHER EFFECTS OF SANITARY WASTES ON RECEIVING WATERS

The third effect of sanitary wastes is to add greatly to the fertility of the receiving waters. This leads to an increased development in the total mass of living things in the water. Algae especially grow in great profusion. This is not a matter for concern as long as they stay alive, but a time always comes - usually in late summer - when the algae will die. Then, in a few days, the enormous BOD of the dead algae depletes the oxygen and the resulting odour may be worse than the smell caused by the raw sewage in the first place.

A key element necessary for plant growth is phosphorous, and most fertilizers contain it. The activated sludge process converts organic phosphorous compounds into a soluble form, so that a well-treated sewage effluent is nothing more or less than a rather watery liquid fertilizer.

There is nothing, unfortunately, that the plant operator can do about this. A number of chemical methods are known whereby the phosphorous can be settled out of solution, but they are expensive. The development of a new, cheap method to reduce the phosphorous content in sewage effluents is urgently needed, so as to minimize the changes brought about by sanitary wastes in receiving waters.

## CONCLUSION

Let us conclude by considering again the duties of the plant operator in the treatment of sewage. It is clear that his responsibilities do not end at the gate of the sewage plant; the success or failure of his works will be reflected in the changes his plant causes to the receiving waters. Not only must the effluent look nice and smell nice when it leaves the plant, but the rivers and lakes must look nice and smell nice after they have received it.

Finally, because plant operators are trained to recognize the changes brought about by the discharging of wastes, I suggest that you appoint yourselves as guardians of your respective watersheds and do your best to prevent other people from fouling your receiving waters. No one would wash his car and then let his children throw mud all over it. In the same way I suggest that you do your best to prevent other people from throwing their sanitary wastes around and so spoiling your effluent.

## BACTERIOLOGY OF SEWAGE

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Division of Laboratories

### INTRODUCTION

Prior to the middle of the 19th century, the sole objective of a sewage disposal system was to do just that - dispose of sewage to avoid the development of a nuisance. This is still an objective but more recently, attempts have been made to treat the material prior to disposal to remove both organic material (dissolved or suspended), and to eliminate disease producing agents such as bacteria, viruses and protozoa.

Human diseases are primarily transferred from man to man by his own infected fecal discharges and in some cases this is the only method of transfer. This disease transmission may be from feces to dust, to flies, to food or water, or to humans directly by contact. Water however has through the centuries played the foremost role in disease transmission. It is a matter of record that when proper water and sewage treatment facilities have been installed in a community, the health of its inhabitants has improved noticeably and their life-span has been extended.

Suffice it to say that floc formation and settling plays a large part in the removal of viruses and effluent chlorination diligently enforced removes bacteria, some viruses and other disease agents. It is not the intention of this lecture to discuss disease organisms however, although any lecture on the microbiology of sewage requires mention of these dangerous agents.

Another objective of a treatment system is to prevent the development of a nuisance condition by transforming dissolved and suspended organic materials into stable mineral compounds and cell contents. Bacteria are the principle agents active in these processes.

The decomposition of organic materials by bacteria is comparable to digestion in the intestine of animals. All digestive processes are brought about by micro-organisms in an effort to make use of the organic material as a source of energy or as building materials for microbial protoplasm. If this digestion takes place under aerobic conditions, the organic material may be oxidized to its end products or be assimilated into microbial tissue. If the conditions are anaerobic, it is impossible for the complete oxidation to take place and intermediate malodorous compounds may accumulate. Hydrogen sulphide, for example, ordinarily cannot undergo oxidation under anaerobic conditions. In the presence of oxygen, however, there are bacteria that readily and rapidly oxidize hydrogen sulphide to water and sulphuric acid, neither of which has any odour. (Chemical oxidation is, of course, also possible.) Therefore, all that is necessary in order to prevent the accumulation of disagreeable odour is to furnish organisms, decomposing waste materials, with adequate quantities of oxygen. This transformation of the easily decomposable organic materials into the end products of bacterial metabolism (that is to  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{H}_2\text{SO}_4$ ,  $\text{HNO}_3$ , and so forth) is generally spoken of by the biologist as mineralization but is designated by the sanitary engineer as stabilization.

Without microbial activity, chemical break-down of sewage would be a very lengthy and costly process. Plant operation merely caters to the requisites of these micro-organisms and a study of bacterial activities should help to understand the treatment facility.

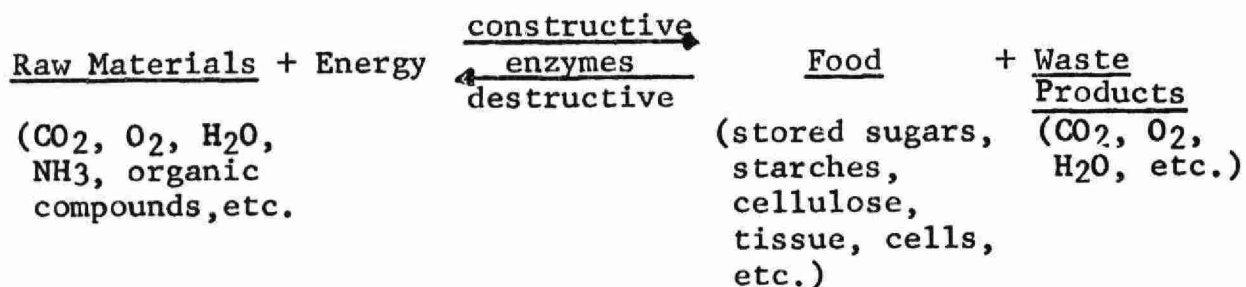
Micro-organisms in the sewage plant break down solids and remove dissolved materials from the liquid portion of sewage. They feed on sewage and waste substances in order to grow and reproduce, and as a result produce a nuisance-free effluent. The method by which microbial activity accomplishes this will be the main subject of the following discussion.

The nature of a bacterial cell must be considered to understand the enormous task that micro-organisms carry out. The composition of sewage is also important. This latter will be dealt with by others, and suffice it to say that a large portion of sewage is organic, i.e., it contains

a combination of carbohydrates (sugars), proteins and fats.

Bacterial metabolism and bacterial activity may be considered identical in meaning for this discussion. Bacterial metabolism, insofar as it involves biochemical changes taking place in sewage treatment, involves the intake, digestion and assimilation of food in and by the cells, and the transformation of the potential energy in food to kinetic energy with which the organisms accomplish work, and eliminate the waste products formed. More simply, metabolism is the study of the feeding habits of bacteria through which cells are formed, energy for life is obtained, and by which they eliminate their wastes. In general, metabolic processes may be divided into two categories, first, those involving constructive processes; second, those involving destructive processes. Constructive processes utilize energy; while destructive processes liberate energy. Within a bacterial cell, both of these processes take place at all times. The former must exceed the latter or otherwise growth can take place only at the expense of energy stored in the form of reserved food. It is well to keep in mind that the metabolism of most of the micro-organisms with which this discussion is concerned, differs little fundamentally from the metabolism of animals, including man.

Metabolic processes may be regarded in the following manner:





WHERE DOES ORGANIC MATTER COME FROM

Plants containing chlorophyll, (the green colouring matter of higher plants) possess the peculiar property of being able to absorb radiant energy from the sun, utilizing it to carry out constructive processes to produce sugars which are stored in leaves. Simultaneously plants absorb water from the soil through their roots, and carbon dioxide from the atmosphere through the pores in their leaves. Through these compounds plants can further construct compounds from which fats, proteins, and other plant constituents are formed. Plants, therefore, are capable of producing organic matter in which the sun's energy is stored.

However, a plant must not be thought of as merely carrying out constructive processes resulting in the gradual accumulation and storage of potential energy in food. Liberation of stored energy through destructive changes is essential to all life processes and is taking place in the plant cells at all times. (This process of liberation is known as respiration.)

Animals derive the energy to carry out their constructive processes from potential energy stored in the organic food they eat. In this manner potential energy stored in plant and animal tissues ingested by animals will form further animal tissues, the net change resulting in an enormous change of stored energy.

BACTERIA

Bacteria have been defined as plants, though their metabolism more closely resembles that of animals. The majority of the better known bacteria derive their energy from the potential (stored) energy bound up in organic compounds. Most of the food utilized by bacteria is in the form of solids or dissolved organics. Bacteria possess no mechanism for ingesting solid material. Most animals are capable of taking into their digestive tracts solid foods and transforming them into a soluble state through the process of digestion. In the case of bacteria, the digestive process concerned in transforming insoluble foods into a

soluble condition must take place outside the organisms body. The chemical changes involved in digestion are the same whether they take place within or without the body of the organism. All such changes are accomplished through the intervention of so called "digestive juices" discharged within the digestive passages, or excreted into the surrounding medium. The active agencies in digestive juices are enzymes, that is, organic catalysts produced by the living cells. It is known that enzymes are destructive in their action, are sensitive to many acids, bases, salts and other compounds, and are easily affected by physical agents such as heat. The speed of change in composition of material attributable to enzymes depends upon the concentration of the enzyme. Enzymes are also known to be specific (for one type of molecular structure) in their reactions.

The action of extracellular and intercellular enzymes is somewhat different. The former are of value primarily in the activation of the reaction involved in changing insoluble foods into a soluble state, or reducing the size of the molecules of food so that they can readily "diffuse" into the cells. Intercellular enzymes continue the break-down of the molecule and in the process liberate energy and reduce the molecules to a size that can be used as building blocks in the construction of the organism's or cell's body.

#### BACTERIAL RESPIRATION

Respiration has been defined as those biochemical processes taking place in a living protoplasm, whereby energy is made available for life processes. This definition covers that phase of activity of an organism through which energy is obtained to carry on the process of growing and allow for the discharge of waste product. In higher plants and animals, the overall process is measured in terms of the uptake of oxygen (a raw material) and the liberation of carbon dioxide (a waste product). In this case, oxygen is presumably being utilized to bring about the oxidation of some food substances, whereby carbon dioxide is liberated and energy is made available to the organism to carry out its metabolism. (Early theories postulated that synthetic biological processes could



take place only through the intervention of atmospheric oxygen indicating that all organisms were classed as aerobic or needing oxygen to carry out their life processes. However, Louis Pasteur proved that bacteria could carry on their metabolic activities in the absence of free atmospheric oxygen. He proved that energy for synthetic processes of life could be derived from fermentative reactions under anaerobic conditions. More recently it has been shown that there are numerous respiratory processes which do not involve the utilization of molecular oxygen.) Nevertheless, most, if not all, of the energy liberating changes are basically oxidative (aerobic) in nature; as a result all such processes are frequently spoken of collectively as biological oxidation. Therefore microbial respiration is of paramount importance in all sewage treatment methods.

The biological changes involved in microbial respiration are exceedingly complex. To aid in gaining a mental picture of the process, numerous chemical reactions have been suggested, whereby the potential energy of various complex organic substances might be transformed into active energy for synthetic metabolism. Most of these are too involved for a brief discussion of this nature. Suffice it to say that all respiratory processes are destructive in nature and that the general tendency is towards the transformation of organic compounds into the inorganic state, processes to which the term mineralization or stabilization has been applied.

#### UTILIZATION OF FOOD

Micro-organisms require food for the identical purposes that man does, namely, for growth and construction of new protoplasm, for repairing old worn out protoplasm, and for supplying energy with which to carry out these energy absorbing processes. Since the total mass of an individual bacterial cell is never very great, even under ideal growth conditions, the quantity of food required for this purpose is relatively small. However, the respiratory activity of an organism is more closely related to its external surface area than to its volume because of the location of extracellular enzymes. The ratio of surface

area to volume in bacteria is extremely wide. If we take surface area as a measure of activity - consider the following - a cubical organism 1 mm square would have a volume of 1 cubic mm with a surface area of 6 square mm, giving a ratio of surface to volume of 6. If this cubical organism were divided into cubical portions 1 micron on a side, there would still be 1 cubic mm of volume but the overall surface would be 6 billion square microns (or 6 thousand square mm) giving a ratio of surface volume of 6 thousand.

This situation exists in the spongy zooglear masses. It is obvious that the exposed surface of this given volume of bacteria is thousands of times greater than that of an equal volume of macroscopic (larger) organisms. (1 micron = 1 over approximately 400 thousands of an inch.) It is this enormous exposure of surface with the corresponding high respiratory activity that enables micro-organisms to accomplish the marked changes that take place in sewage treatment during relatively short periods of time. As mentioned earlier, extracellular enzymes produced on the surface of bacterial cells would correspondingly be enormous in quantity.

The actual specific compounds that may be utilized as food by bacteria are almost unlimited. A statement has been made that every organic compound occurring naturally or produced biologically can be utilized as food by some micro-organisms. If some provision for the destruction of organic matter were not made by nature, any such compound would gradually accumulate and the surface of the earth would eventually become so impregnated with it, that life in its present form might become impossible. The greater the variety of extraneous substances present in sewage, particularly of an organic nature, the larger the variety of micro-organisms that will find suitable foods for growth. There are even specific groups in bacteria that are capable of utilizing substances ordinarily regarded as unavailable to any form of life, such as woods, parafins, ammonia, reduced iron, hydrogen sulphide, carbolic acid, methene, hydrogen, nitrous acid, and so on. These substances may function either as food for building or repair purposes, as a source of energy, or for both building and energy.

Organic materials found in sewage, such as vegetables, paper, wood, muscular tissue, and the like, are made up largely of very complex molecules of unknown composition. In the syntheses of these complex molecules by the plant or animal, they are not built up directly from the elements but are assembled from less complex molecules. Just as the smallest train is assembled from two single cars coupled together, so ordinary table sugar is assembled in sugar cane from two molecules of simple sugars. Carrying the simile further, just as the train may be made up of hundreds of individual cars, all of which may or may not be alike, similarly a complex organic molecule may be made up of hundreds of individual molecules of a sugar or of other comparatively simple molecules, all of which may or may not be alike.

Making further use of the above simile, the train of a hundred cars may be uncoupled between any two cars forming a number of smaller trains of equal or unequal size. Similarly a complex molecule composed of hundreds of molecules can be split up into equal or unequal units each forming a complete molecule. This, in brief, is all that the micro-organism (through the agency of enzymes) does in splitting up complex molecules into simpler ones, or in bringing about the initial steps in the decomposition of organic matter. After the complex molecules have been split into small enough units, they become soluble and then can be utilized in the metabolism of the micro-organism.

Since enzymes are specific to a particular biochemical change, the organism must produce a special enzyme to catalyse each chemical reaction. In the human body, the groups of specialized cells known as glands are gathered together to produce these enzymes. Each gland produces a certain set of enzymes to carry out a particular biochemical change. In the microbial or bacterial body, the single cell must produce all of the different kinds of enzymes necessary in the metabolism of the organism. Since all biochemical changes are the result of intervention of enzymes, it is possible for micro-organisms to bring about chemical changes at a temperature of about 20°C. that cannot otherwise be induced at temperatures below 100°C. by chemical reaction alone without enzymatic products.

## THE COMPOSITION OF CARBOHYDRATES

Carbohydrates, or sugars, or organic compounds that are composed of carbon, hydrogen and oxygen, make up a greater part of the organic material of plant origin and hence are a major constituent of the organic matter in sewage. Cellulose, a complex molecule, composed of many glucose (sugar) molecules, grouped together, is the most abundant carbohydrate found in sewage. Cellulose, for example, is insoluble and cannot be readily used by micro-organisms unless it is broken down into its component sugars which are soluble. Therefore, extra-cellular enzymes are produced by the micro-organisms to react with cellulose to break it down into a compound called cellobiose which in turn is broken down into glucose molecules which are soluble and become available for the metabolism or nutrition of the surrounding micro-organisms. We see, therefore, that the primary digestive enzymes in microbial decomposition are secreted by bacteria and break down the molecular structure of food (sewage) outside the cell. Up to this point in decomposition, virtually no actual destruction of organic matter has taken place, though there has been a reduction in particle size, and little or no oxygen has been used up in the processes involved.

When the sugar molecule is absorbed into the microbial cell from the surrounding solution, it immediately undergoes complex thermo-chemical alterations, whereby the potential energy of the molecule is transferred into active or kinetic energy necessary for bacterial life processes. A small portion of the sugar in the form of some decomposition product may be utilized by the organism for building and repair purposes, but the major portion functions as a source of energy. This transfer of stored energy in the ingested foods, to kinetic energy to be utilized by the microbial body, is most efficient when it involves aerobic (oxygen requiring) respiration. This is why free atmospheric oxygen is essential in the life processes of aerobic organisms. Similar reactions take place with other carbohydrates existing in sewage.

The composition of fat, oils, waxes and the like, although of a different structure, eventually undergo the same steps in the decomposition, whereby the molecules

become smaller and smaller until eventually they may be either oxidized to the final product carbon dioxide and water, or resynthesized into microbial tissue. Here again the basic changes involved are identical to those taking place in the alimentary tract of body tissue of man.

### DECOMPOSITION OF PROTEINS

The third of the major groups of organic compounds found in (food) sewage, are proteins. Proteins differ in elementary analyses in that they contain both nitrogen and sulphur and sometimes phosphorous in addition to carbon, hydrogen and oxygen. Proteins are present to a limited extent in all plant and animal tissue and are abundant in muscular or lean meat tissue and in seeds of certain plants, particularly in the legumes. Proteins like carbohydrates and fats are not synthesized directly from the elements but are assembled from other complete molecules.

The protein molecule is usually very large being composed of the variable number of different amino acids. Some proteins are soluble but even the molecules of these are too large to diffuse through membrane of the microbial cell. Consequently, they cannot be absorbed by living organisms without primary splitting of the complex molecule. The enzymatic stages involved here are similar to those mentioned in detail in the section under The Composition of Carbohydrates. The end products of complete oxidation of proteins are carbon dioxide, water, nitric and sulphuric acid, and also phosphoric acid where phosphorous is present.

### SUMMARY

1. Sewage treatment is biochemical in character and micro-organisms are the active agents in the mineralization of solids and dissolved solids.
2. The mechanism which enables a rapid mineralization of wastes at normal temperatures is the enzyme system.

3. Extracellular enzymes of organisms aid in the breakdown of solids into soluble particles.
4. Intercellular enzymes of organisms use the solublized substances to build cell body materials and stable compounds in the presence of oxygen.
5. All treatment processes merely cater to microbial activity.
6. Micro-organisms are not acting in a special way in sewage treatment, but are merely doing the job for which they were intended.



THE CHEMISTRY OF SEWAGE TREATMENT AND  
INTERPRETATION OF ANALYTICAL RESULTS

I. M. Gray

Division of Research

In order to understand the process of sewage treatment, it is first necessary to have some knowledge of the composition of sewage, its chemical nature, and the ways in which the many components of sewage are converted to acceptable materials.

Chemically, sewage is composed of inorganic and organic compounds carried in water. The inorganic materials such as sand, grit and dissolved chemicals are generally inert and are thus not subject to biological decomposition. However, the bulk of the waste material in sewage is organic and may be decomposed either by heat, chemical or biological action, to simpler chemical compounds acceptable for discharge to receiving waters.

ORGANIC COMPOUNDS

The organic chemicals in domestic sewage originate from various sources. These consist of human wastes, kitchen wastes, and laundry and bathroom wastes. Additional and usually much stronger wastes enter sewage systems from industrial sources such as dairies, canning plants and many other types of industry.

Organic compounds are those comprising atoms of carbon, hydrogen, oxygen and sometimes nitrogen, phosphorous or sulphur. In chemistry these elements are depicted by the following symbols:-

Carbon	-	C	Nitrogen	-	N
Hydrogen	-	H	Phosphorous	-	P
Oxygen	-	O	Sulphur	-	S

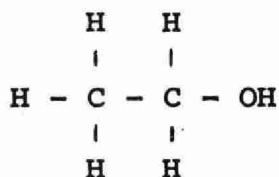
Using these atomic symbols, everyday compounds can be represented as follows:-

Water             $H_2O$              $H-O-H$

The hydrogen atoms are both joined to the oxygen by a bond or coupling, represented by the dash. This coupling is actually effected by electron position and charges.

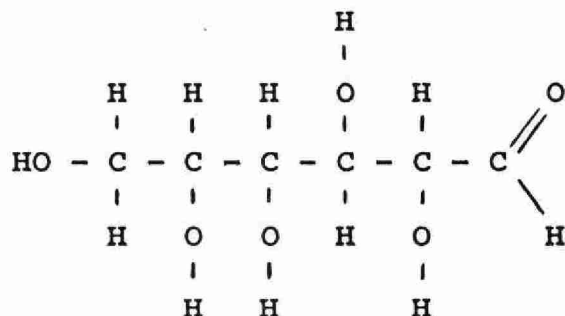
Similarly:

Alcohol (drinking variety) is  $C_2 H_5 OH$



and,

Sugar,  $C_6 H_{12} O_6$





The organic compounds normally present in sewage are carbohydrates, proteins, fats and detergents.

### Carbohydrates

A good everyday example of a carbohydrate is starch, as found in bread or potatoes. It is a huge chemical compound comprising carbon, hydrogen and oxygen, and is made up of many molecules of sugar as shown previously.

### Proteins

Protein is found in bread, eggs, meat and many other foods; chemically it is made up of carbon, hydrogen, oxygen and also nitrogen and sometimes sulphur. The atoms are joined together as before and again these are very large chemical structures. It is the organic sulphur compounds that cause most of the foul odours associated with septic sewage.

### Fats

Normally fats are constructed of a number of fatty acid groups joined together, again comprising carbon, hydrogen and oxygen atoms. In sewage these substances originate from butter, milk, cooking oils, waxes (paper cups) and animal fats in meats. The biological decomposition of fats also accounts for a proportion of the unpleasant smells associated with decomposing foods and sewage.

### Detergents

These are such chemicals as L.A.S. (linear alkylate sulphonates) with large quantities of chemical filler. It is this filler, generally a polyphosphate, which is thought to contribute considerably to the eutrophication of the lakes and rivers.

To simplify the sewage treatment process still further it should be remembered that all these chemical compounds exist in sewage as suspended, dissolved or colloidal solids, and as such are treated in different parts in the sewage plant.

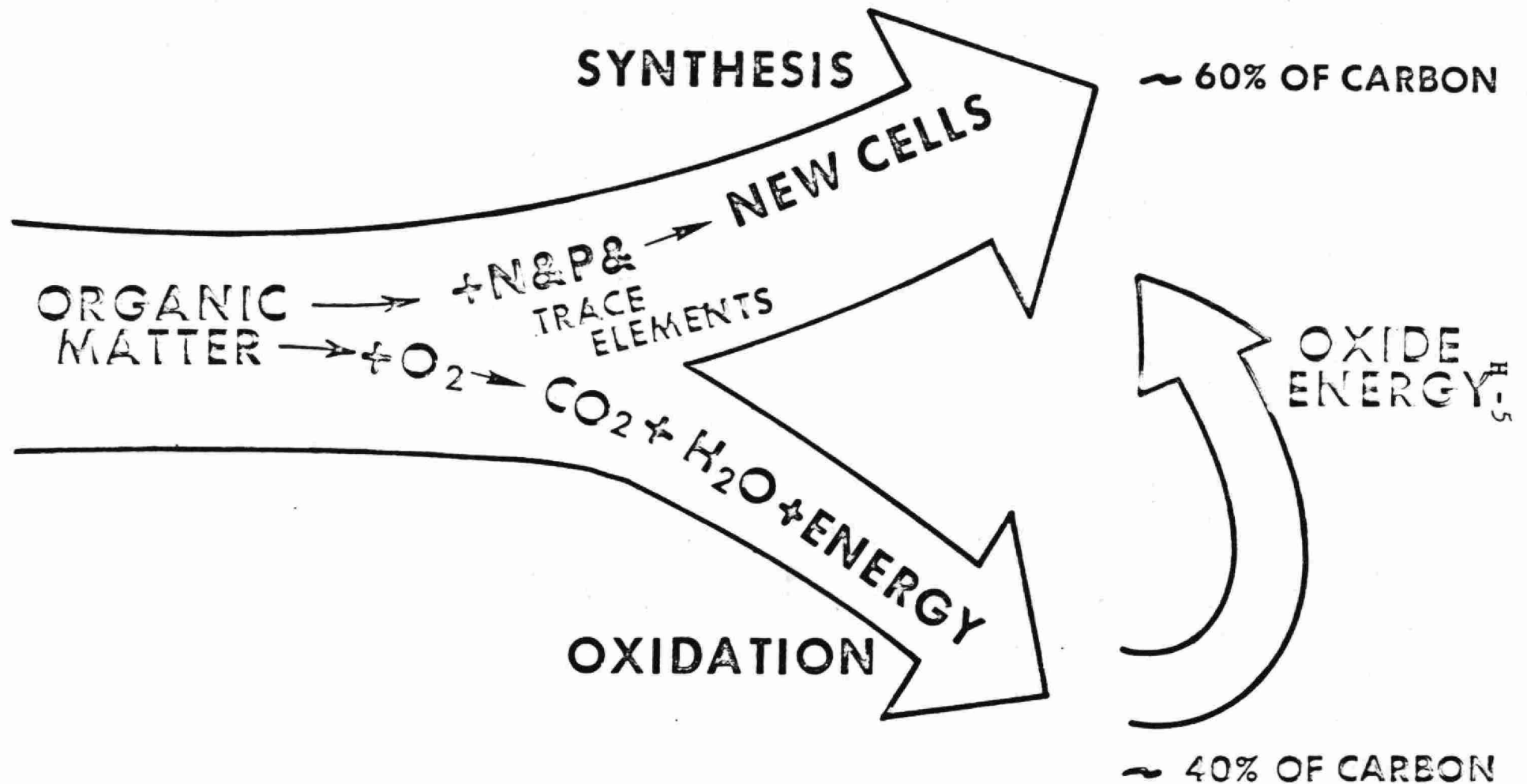
In the sewage plant the sewage normally passes through bar screens which remove the large insoluble materials; these are then taken away and burnt or buried. The inert inorganic solids are removed in the grit separators, and the remaining suspended solids are then removed in the primary clarifier by allowing them to settle out.

The dissolved and colloidal solids then pass on to the activated sludge system. As you will know, the activated sludge tank is simply a large tank containing a sludge comprised of many microscopic organisms to which oxygen in the form of air is supplied in a number of possible ways. The diagram (Fig.1) demonstrates what happens when the organic compounds are brought into contact with the bacteria and the oxygen.

The organic matter containing the carbon, hydrogen, oxygen, nitrogen and phosphorous as described earlier, is used up as food for energy and for new bacterial cell production. The nutrient materials, nitrogen and phosphorous,

Fig.1

# GENERAL METABOLIC REACTION



necessary to all life processes, are partially utilized again in new cell production. Thus the large molecules described earlier are by a complex process broken down to carbon dioxide,  $\text{CO}_2$ , and water,  $\text{H}_2\text{O}$ . The unused nutrients will be present in the water as nitrates ( $\text{NO}_3^-$ ) and phosphates ( $\text{PO}_4^{---}$ ).

The treated sewage and bacteria are separated by settling and the microorganisms are returned to the activated sludge tanks to treat additional sewage. The clean treated sewage, after chlorination to kill any bacteria present, can be discharged to its receiving waters (rivers, lakes or streams).

The settled solids in the primary clarifiers, now a thick organic sludge, are pumped to the anaerobic digester; here in the presence of different bacteria which live in the absence of oxygen, hence called anaerobic organisms, the organic compounds are broken down. Good mixing and maintenance of the optimum operating temperature of  $90^\circ\text{F}$  to  $95^\circ\text{F}$  by the use of heat exchangers utilizing combustion of the produced methane gas or auxiliary fuel, allows the decomposition of the organic solids. This time the carbon is changed to methane and carbon dioxide, nitrogen converted to ammonia, and any sulphur present will go to hydrogen sulphide.

C  $\longrightarrow$   $\text{CH}_4$ , methane and  $\text{CO}_2$  carbon dioxide

N  $\longrightarrow$   $\text{NH}_3$ , ammonia

S  $\longrightarrow$   $\text{H}_2\text{S}$ , hydrogen sulphide

After approximately 30 days a well stabilized sludge, with all its easily biodegradable organic compounds removed, is trucked away or dried on drying beds or automatic filters.

Alternatively, these same organic solids when removed from the primary clarifier, can be digested aerobically (i.e. in the presence of oxygen) to the same by-products as are produced by the activated sludge process.

#### INTERPRETATION OF ANALYTICAL RESULTS

As can be seen from the brief description of the chemical composition of sewage, it would not be practical to analyze for all the individual chemical components present. Therefore it has been found necessary to find means of evaluating the amount of organic materials entering or leaving the sewage plant. The method most commonly used is the BOD<sub>5</sub> test or Biochemical Oxygen Demand test. This test is conducted in the laboratory over a five day period and measures the amount of oxygen which would be required by bacteria to oxidize the organic materials present in the sewage.

Other and more rapid tests indicating the amount of organics present are the COD test - Chemical Oxygen Demand, the TOD test - Total Oxygen Demand and the TOC test indicating total organic carbon. The COD test measures the amount of oxygen required to chemically oxidize the remaining organic materials and as such, normally gives higher results than the BOD test.

The BOD test, whilst not being the quickest or most reliable method available, does give a value which is indicative of the effect the discharged wastes would have on a stream or river. Thus, the BOD test indicates the oxygen demand of the organic components of sewage expressed

in milligrams per litre. This information, along with the flow data, can be used to calculate the organic load to the plant, the organic load to the aeration system, or the organic load of the waste effluent entering the river or stream. Similarly, it is possible to calculate the efficiency of removal of organic materials by the primary clarifier or the overall BOD removal in the plant. Knowing the amount of oxygen required to oxidize a given amount of BOD, it is then possible to determine whether or not there is sufficient air being delivered to accomplish this, or in the case of increased loads, how much more air would be necessary to accomplish satisfactory removal of organic materials.

Other useful information can be obtained from the determination of the solids content of the waste. These solids can be divided into three groups: dissolved, colloidal and suspended solids. The suspended solids comprise inert materials such as sand and grit, together with the larger insoluble organic materials. Such solids are mainly removed in the influent works and in the primary clarification stage of the treatment plant. Thus the colloidal and dissolved solids, along with a small amount of suspended matter, enter into the aeration section. Most of these solids are assimilated and degraded by the activated sludge bacteria and are thus removed from the system, leaving only the dissolved inorganic and thus inert chemicals present in the treated waste.

pH

Another value which is often required is the pH. This simply indicates numerically the acidity or basicity of the raw sewage, activated sludge or final waste. A pH of 7 is neutral, higher than pH 7 is alkaline or basic and a pH lower than 7 indicates acidic conditions.

Raw sewages are normally in the range pH 6.5 to 8.0 unless altered by industrial waste discharges to the sewers, e.g. soft drink plants will often produce acidic wastes, similarly milk processing plants, breweries and distilleries will often discharge either strongly acidic or basic wastes.

Thus the analysis results of samples requested by your district engineers will usually show:-

BOD values to indicate the organic content.

Total solids, suspended solids and volatile solids results to indicate the solids removals occurring through the treatment plant.

pH values to show if the waste or effluent is too acid or basic.

Possibly if special information is required, values for nitrogen, phosphorous and detergents may also be shown.

OPERATION AND MAINTENANCE OF CONTROL  
AND METERING EQUIPMENT

K. Wheaton

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Today instrumentation is somewhat of a confusing word, depending on a person's acceptance of its meaning. It is sometimes associated with automation, but I like to think of instrumentation as a system of control which can measure a process and control some or all parts of it.

Quite often we mention instruments, which is a particular unit, when what we are actually referring to is instrumentation. We are all familiar with our automatic appliances, such as toasters, clock radios, stoves, furnaces etc. These all have forms of instrumentation inasmuch as they have an automatic control of some process, such as toasting bread, turning on the radio, baking, heating our houses, etc., so it is not such an imposing word after all.

When used in the industrial field, it does measure and/or control a process. Now a process is any operation from pumping water to providing treatment or manufacture of a substance. In the waterworks field, instrumentation will measure the flow of water, control the pressure, pH, chlorine residual, etc., level of reservoirs and, in so doing, will automatically control pumping, filter backwashing, chlorine dosage, alum dosage, etc.

Why is Instrumentation Necessary?

Over the years, the physical sciences have been used to augment our sense of temperature, viscosity, pressure and colour. We are incapable of sensing, within narrow limits, differences in temperature, speed, colour, or light intensity. Therefore, we have produced mechanical aids that never get tired, seldom go on strike, and that not only are extremely accurate and sensitive in their response, but keep those characteristics for extended periods of time.



As individuals, we cannot maintain maximum efficiency for more than a very short time. If our senses were sufficiently accurate, which they are not, more than three people, per 24-hour day, would be required to monitor each station or group of stations, that one person could sense and keep under control on any one shift.

Here we are concerned with that instrumentation which will help us improve and maintain the quality of water which we are supplying to the water system. In the very simplest system we are merely pumping from a well or other sources of water to a reservoir or tower, while in the more complex systems we will pump from an intake, through a filtering or treatment system, to another pumping station and into a final system or reservoir.

As with most things we do, we want to know what we are getting and the cost of the operation. To do this we must naturally know the flow or quantity of water supplied, and if treatment is required, to automatically control the quality.

The first thing to do is to measure the flow by means of a flow meter operated mechanically, or by differential pressure types. The mechanical type we are all familiar with, since probably we all have one in the basement of our houses, on which we are billed for our consumption of water. The differential pressure types, which we deal with here, allow us to control our system more easily and we will examine several methods of how this is done.

Pressure is force per unit area, e.g. pound per square inch or pound per square foot. A common way of measuring this is by use of a manometer which balances a column of liquid in static equilibrium. If we take a piece of glass tubing and bend it to form a 'U' and fill it partially with a liquid, we then have a very simple form of manometer. It is one of the most accurate ways of measuring relative pressure.

With a simple bent tube filled with some liquid such as water or mercury and open at both ends to atmosphere, we note that the liquid will balance so that both levels are equal above a reference line. (Diagram 1A).

Anywhere in the tube we have an equal pressure point to another at the same level from the reference line. It does not matter that one side of the tube is larger than the other as both are subject to the same pressure. All points at equal distance from the reference line in the liquid are subject to the same pressure (Diagram B).

When we introduce an external pressure to one leg, the other remaining with the same pressure, we find that the liquid in one leg will go down while the other goes up. If we take a point  $p_a$  in the short leg and point  $p_b$  in the long leg that are equal levels above the reference line and point  $p_c$  to represent the distance from  $p_a/p_b$  to the level of the short leg, we find that equal pressure is represented on  $p_a$  by  $p$  external plus  $p_c$ , and on  $p_b$  by  $p_l$  plus  $p_c - p_i$  being the pressure of the higher column of liquid. The distance between the lower and higher points of the liquid,  $h_i$  measured and applied to the specific gravity of the liquid will tell us the pressure applied in respect to atmospheric pressure. If we apply two pressures the distance  $h_i$  will tell us the differential pressure on the system.

Differential pressure types of instruments use a change of pressure to determine velocity and hence flow. The principle used here is that a flow of liquid through a constriction in a pressure conduit results in a lowering of pressure at the constriction. This pressure change is proportional to or reflects the velocity of the fluid flowing through the restriction.

The device used to first provide this differential pressure is known as a Primary Device, and the most common forms are:

- Orifice Plates
- Venturi Tubes
- Dall Tubes
- Pitot Tube
- Flow Nozzle
- Elbow Meter

All of these devices use a change in pressure and operate either a manometer type of instrument or a differential pressure transmitter.

The differential pressure method of measuring flow is probably the most common. However, flow measurements can be made in open channels by the use of a Parshall flume or the use of a weir plate. With a Parshall flume it is common to use a stilling well and float which in turn will indicate the level of flow through the flume. To measure the flow over a weir, a bubbler tube can be used and with a fixed discharge of air, the head pressure on the bubbler tube will be an indication of the flow.

By the use of suitable levers, gears, etc., this change of pressure or level can be indicated as a flow value, it can also record or transmit the information to another point where it can indicate, indicate/record, indicate/record/control, functions such as pumps.

The primary device, along with a transducer which is merely a means of changing one type of signal to another with an indicator, is known as a transmitter. That unit which receives this signal and either indicates, records, or indicates and records, is known as a receiver. These units may be in the same box cabinet or they may be separated by a few feet or a few miles. When the information is transmitted to another location it is known as telemetering.

The transducer along with the associated units are known as secondary devices. These secondary units are divided into three groups, namely:

- Mechanical
- Pneumatic
- Electrical which includes electronics

The mechanical type of instruments are operated by rods, gears, linkages and cables connected to the pressure take off on the primary devices. This, of course, eliminates lengthy piping arrangements which must be leak-free. Mechanical units usually allow much flexibility in that portions of the unit can be removed and replaced without disrupting the flow of the material being measured. Disadvantages are in the lag of the instrument due to inertia and friction of the mechanical parts, slippage in the linkage wear and breakdown of the moving parts and it does require considerable lubrication.

The pneumatic type of instruments, while using mechanical linkages and parts for indication, are using a varying controlled-air pressure ranging from 3 to 15 p.s.i. This signal can be transmitted by piping over distances up to 1500 feet to operate the required instrument. The advantages of this system is that the installation and maintenance costs are low while a continuous signal output with an extensive sensitivity to change in the variable being measured is provided. The main disadvantage is the relative short distance the signal can be transmitted and that a clean dry air supply is required.

Electrical types of instruments will naturally use some mechanical linkages for indication, but the signal is an electrical current or voltage change. This can be transmitted over great distances between the transmitter and receiver, with little loss of signal strength or a time lag that is apparent in other systems. The cost of this type of system is usually a little higher, but recent advances are causing it to be used more frequently in the smaller systems of control with a consequent decrease in cost.

To return now to the pneumatic type of instruments, you will note that there are two illustrations of differential pressure transmitters. In the Bourdon tube type the signal pressure is applied to the element, and it is the twisting effect of the Bourdon tube which is used to provide an indication or to do some other work.

With the bellows type of differential pressure transmitter use is made of a force beam. This beam is set on a pivot and at one end two bellows are placed for the two pressures of the signal, and at the other end there is a balancing bellows with a 'flapper' nozzle, air supply and indicating gauge. With a change in the pressure at the low side, there is a corresponding change in the position of the beam. The changing position of the beam opens or closes the orifice through which a constant air supply is flowing. The balancing bellows provides a constant pressure to the force beam according to the position of the beam in relation to the orifice. This reflected pressure is used to give an indication of the pressure applied to the force beam and is in turn a direct relation to a flow measurement.

The indication of flow as provided by the d/p transmitter can be used to operate an electrical type of signal transmission. One type of electrical instrument uses a revolving cam across which an arm rides and it is the length of time which the arm is on or off the cam which gives the pulse duration of the electrical signal. This signal at the receiver operates a magnetic clutch arrangement, which will move the indicator up or down according to the change of pulse duration.

Another type of electrical instrument uses a variation in current caused by a change in a magnetic field, or a change in position of a potentiometer. When the position of the iron core is changed in the magnetic field the flux density is changed causing a change in the current flowing in the external circuit. This also applies to the change of the position of the arm of the potentiometer, which will change the current flow in that leg of the bridge circuit.

The electrical instruments are becoming smaller due to the use of transistors and also are becoming cheaper by the more prevalent use of this type of unit.

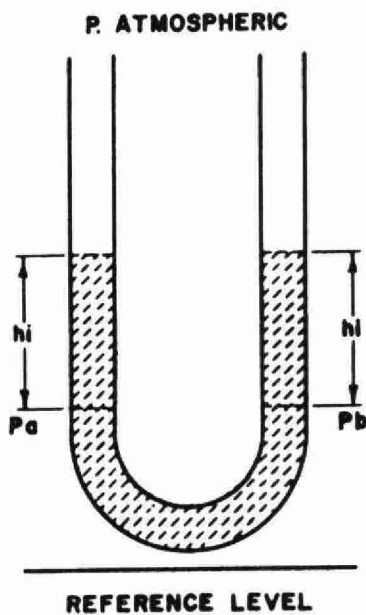
While we have covered a brief outline of instrumentation in regards to flow measurements, we must not forget the other measurements and controls that are necessary. As mentioned earlier, it may also be necessary to control the addition of chemicals to the water or to control a filtering process. The control of chemicals to the water may be done by continuous sampling or measuring for chlorine content, pH, or other required information, and these measurements, through an instrument controller, will maintain a set value or dosage.

The number of pumps required to maintain a certain level of water in a reservoir or tower can be controlled by the rate of flow as indicated by any one of the flow indicators, by means of suitable control circuits. The automatic backwash of a filter can be done by the measurement of the pressure across the filter bed, and at a predetermined value will automatically shutoff the flow of water through the filters and proceed with the backwash operation.

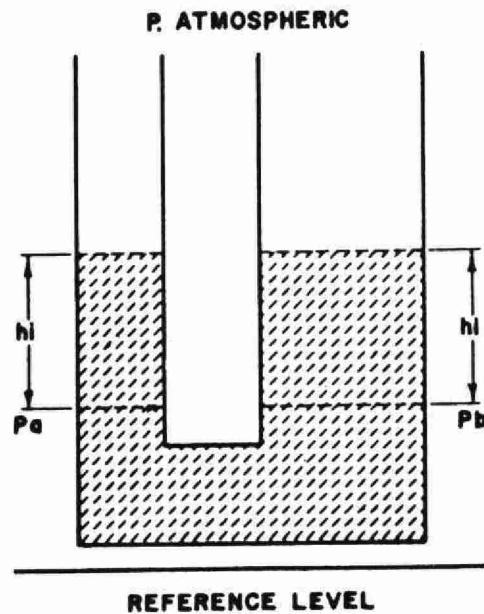
Instrumentation does require a trained technician to maintain the instruments in calibration and repair. However, the principles of operation are simple and can be understood by the operator. This understanding will assist in determining the limitations of the equipment and what may be done in a particular problem. It must be remembered that all flow instruments are only accurate to 1% in the 20 to 80% range, 5% in the 10 to 20% and 80% to 90% range, and cannot be considered accurate below 10% scale.

It is not our intention to continue the 'little black box' theory in regards to instrumentation, but to help disperse the mystery to allow the operation of the instruments to be of some importance to the operator.

I - 8  
**DIAGRAM - I**

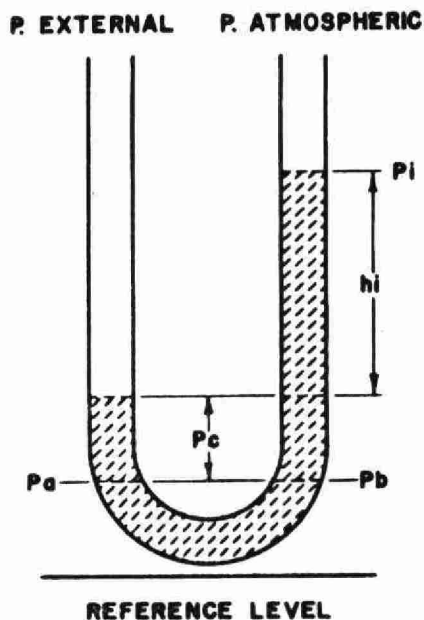


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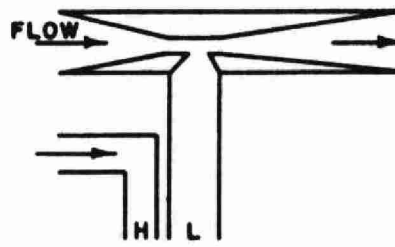
**B**

**U-TUBE MANOMETER**

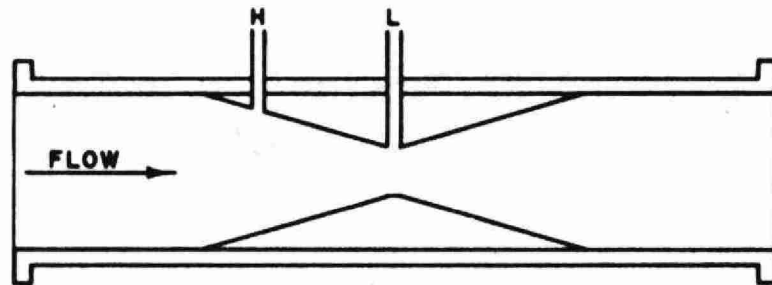


**C**

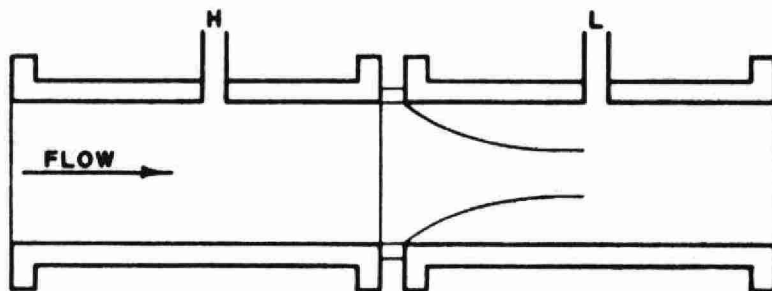
- A — PRESSURE BALANCE ANY SET OF POINTS OF EQUAL HEIGHTS ABOVE REFERENCE.**
- B — PRESSURE EQUALITY OF POINTS AT SAME HEIGHT ABOVE REFERENCE INDEPENDENT OF SIZE OR SHAPE OF LEGS.**
- C — PRESSURE DIFFERENTIAL SHOWS LIQUID RISES IN LEG SUBJECTED TO SMALLER PRESSURE.**



PITOT TUBE



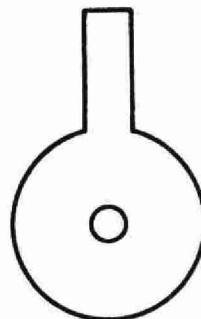
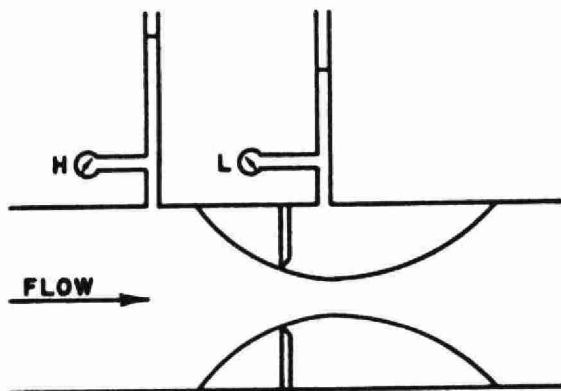
DALL TUBE



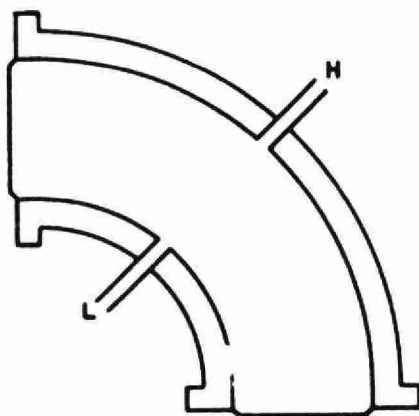
FLOW NOZZLE



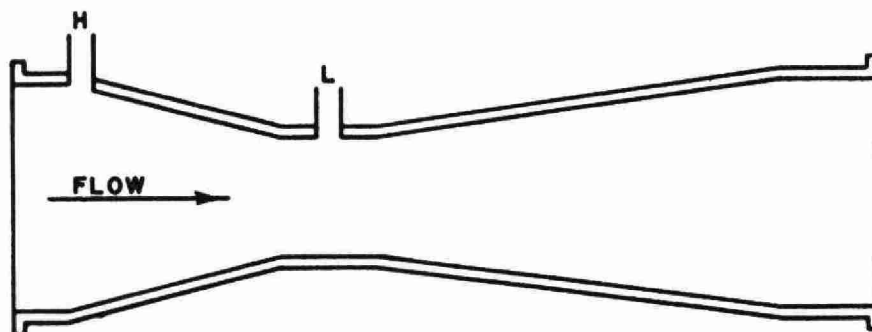
I - 10



ORIFICE PLATE

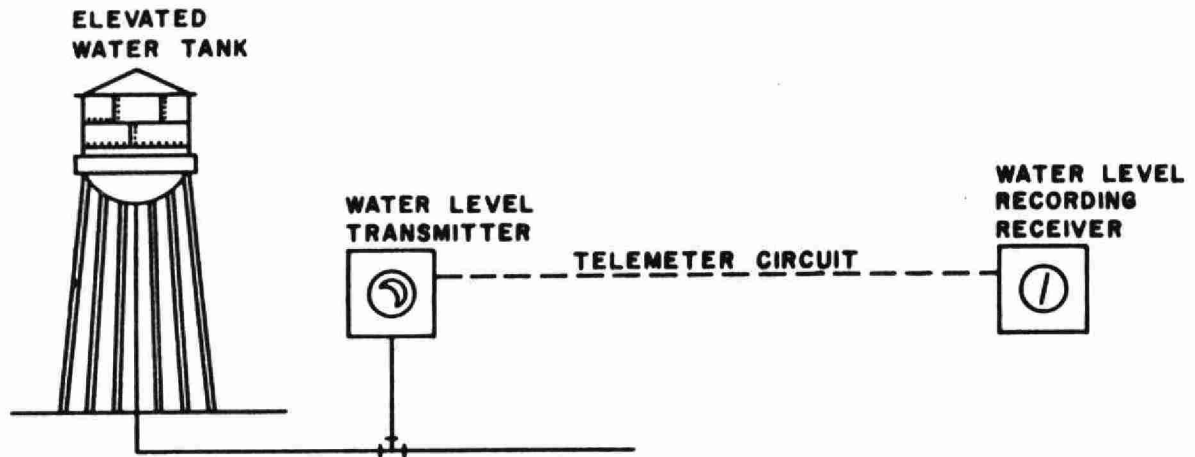


ELBOW METER

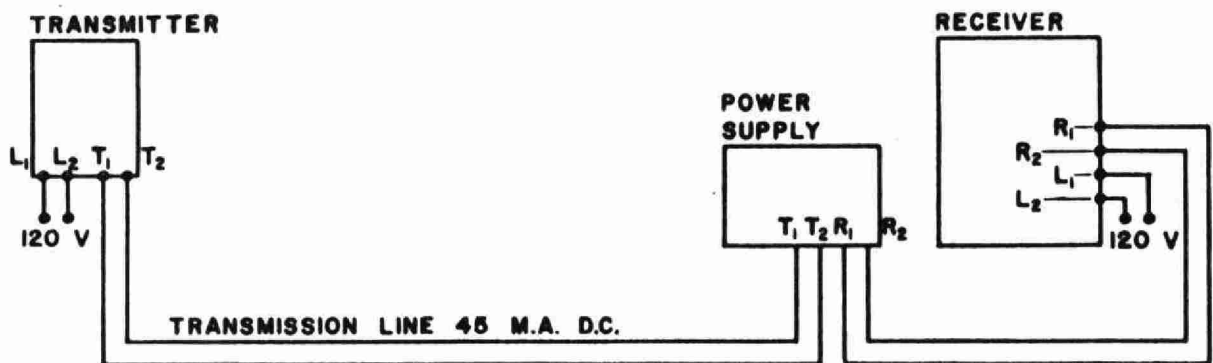


VENTURI TUBE

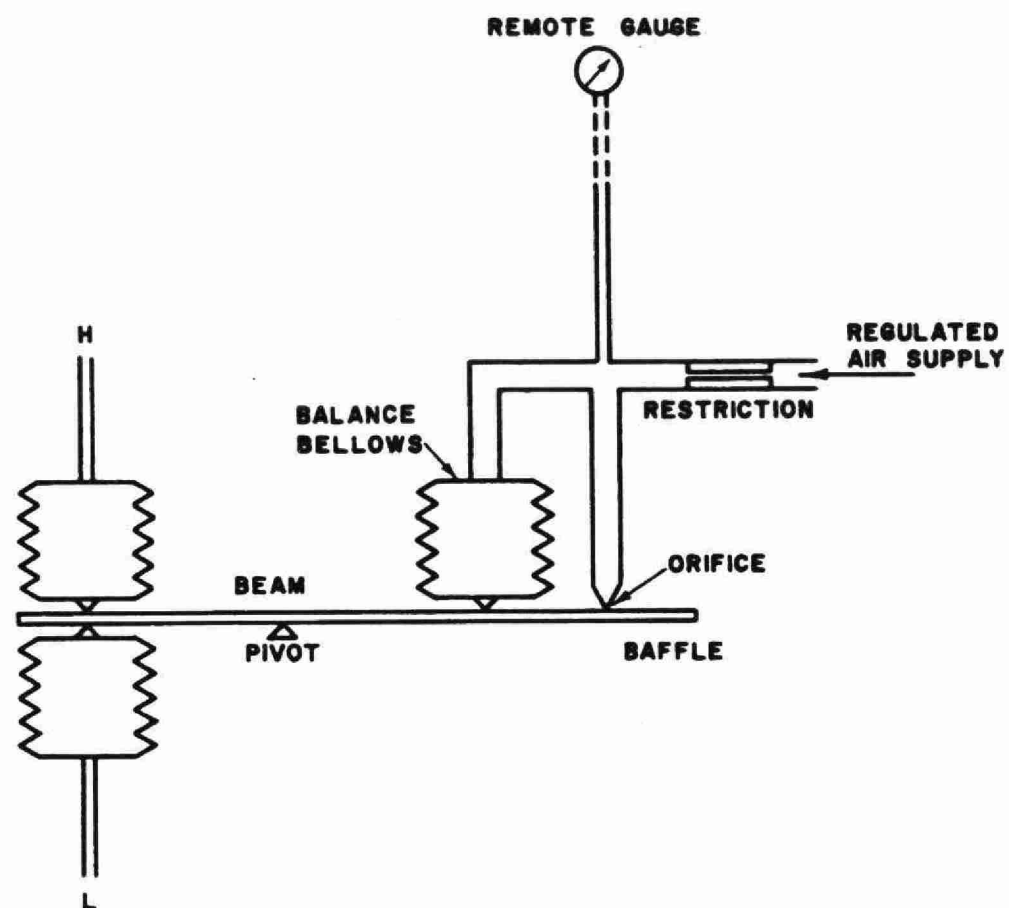
# REMOTE MEASUREMENT OF LEVEL IN WATER TOWER USING ELECTRIC TELEMETER



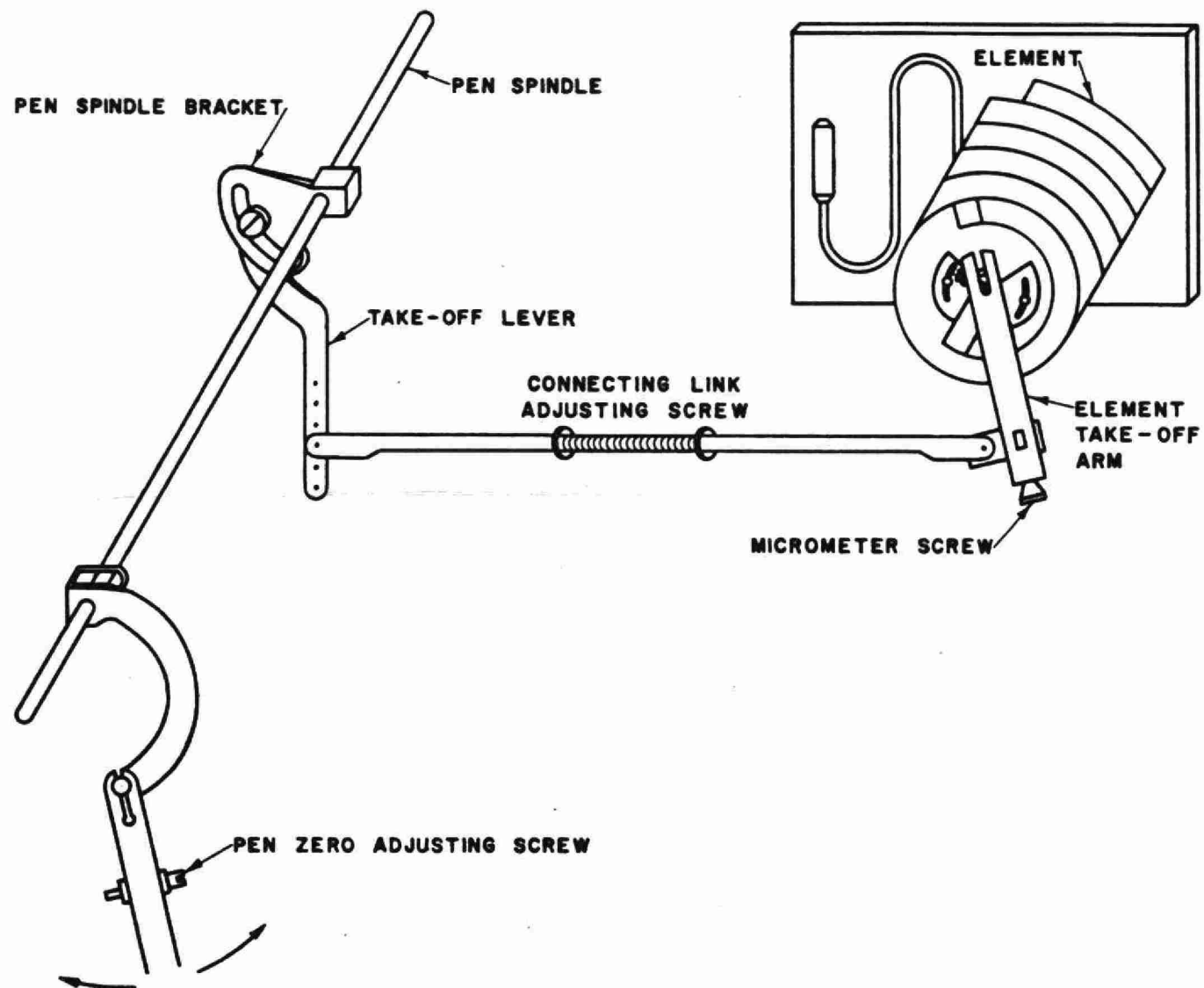
## WIRING DIAGRAM OF TYPICAL METAMETER CIRCUIT

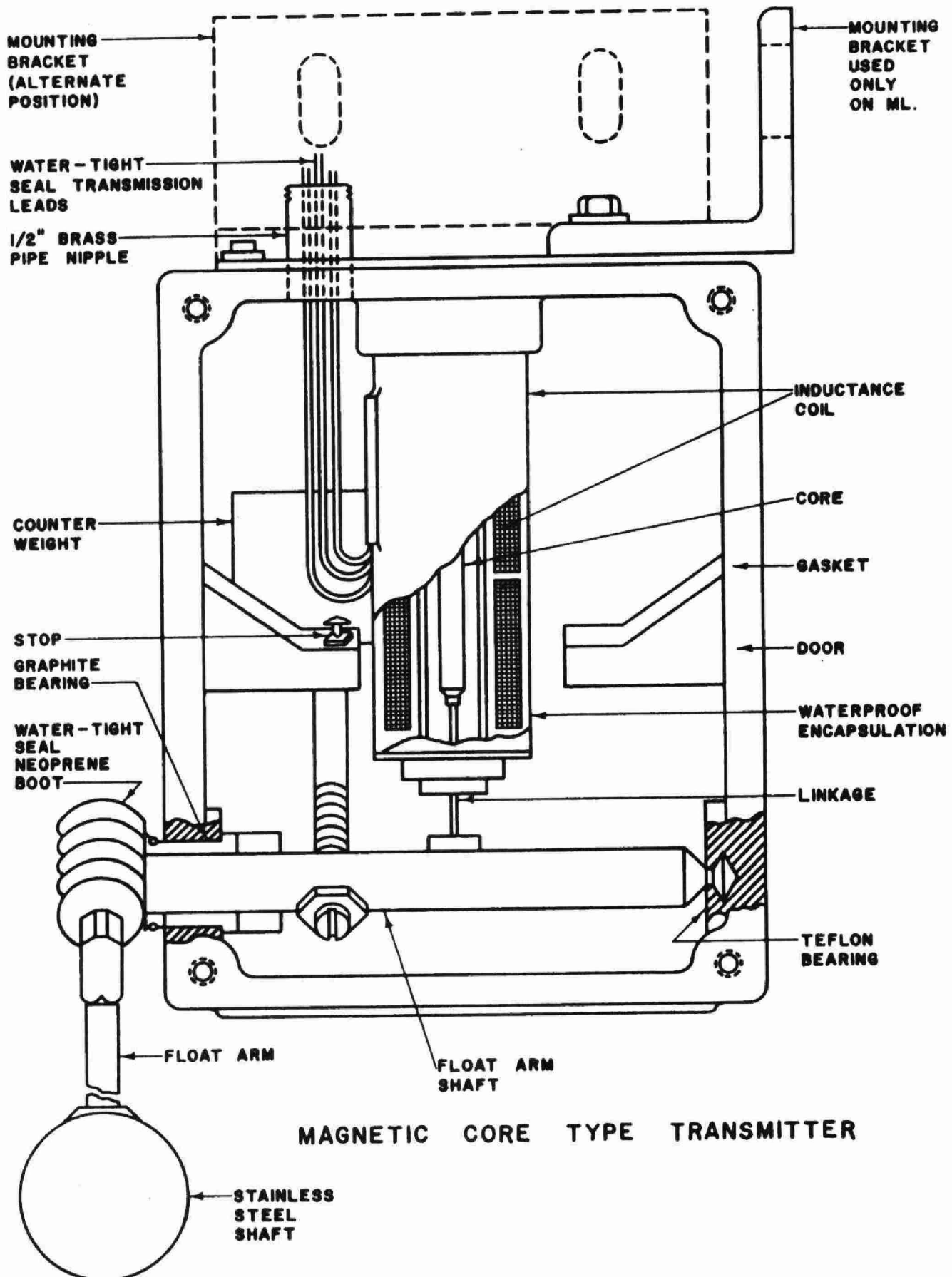


## BELLOWS TYPE DIFFERENTIAL PRESSURE TRANSMITTER



## BOURDON TUBE TYPE OF A DIFFERENTIAL TRANSMITTER





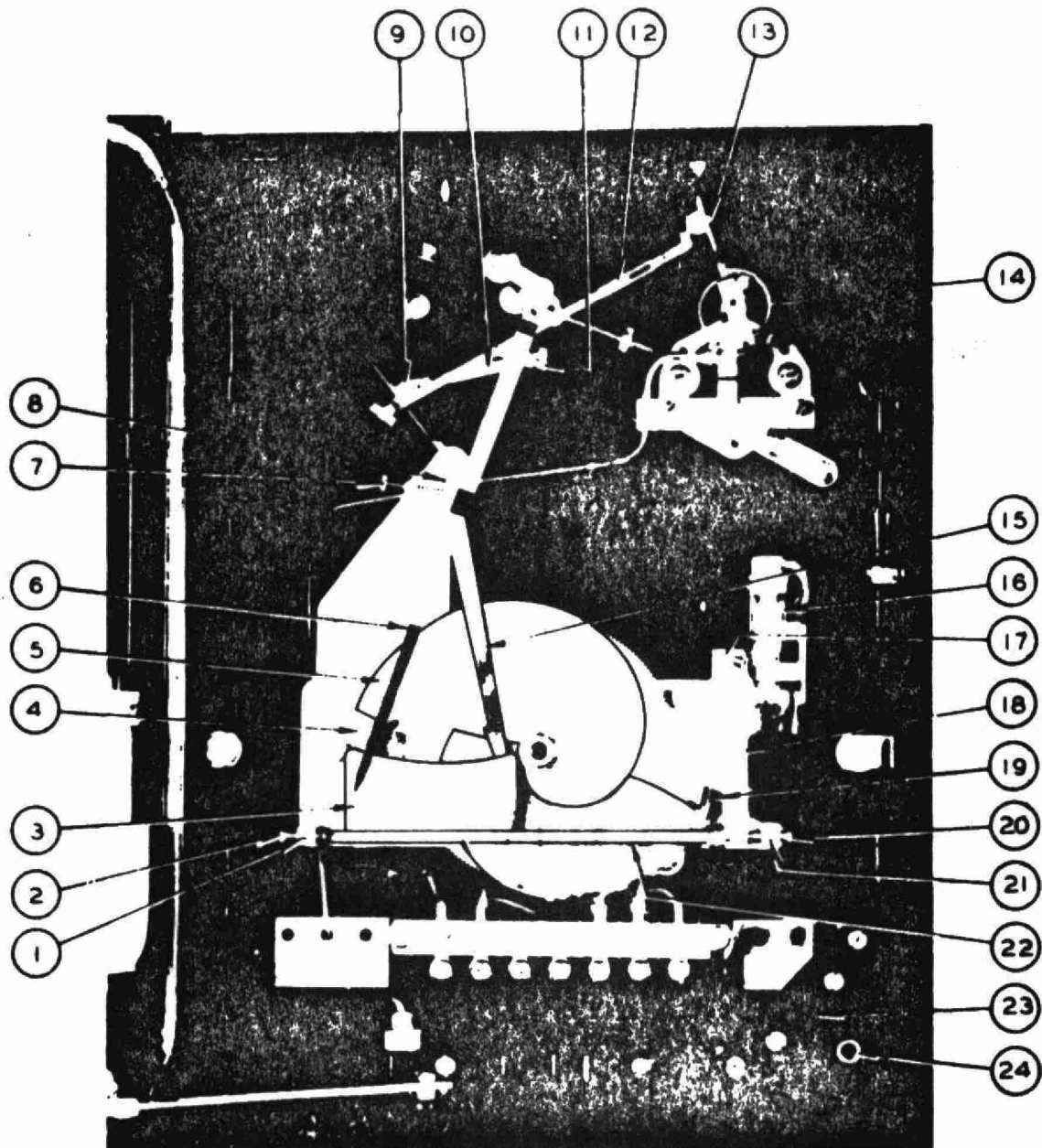
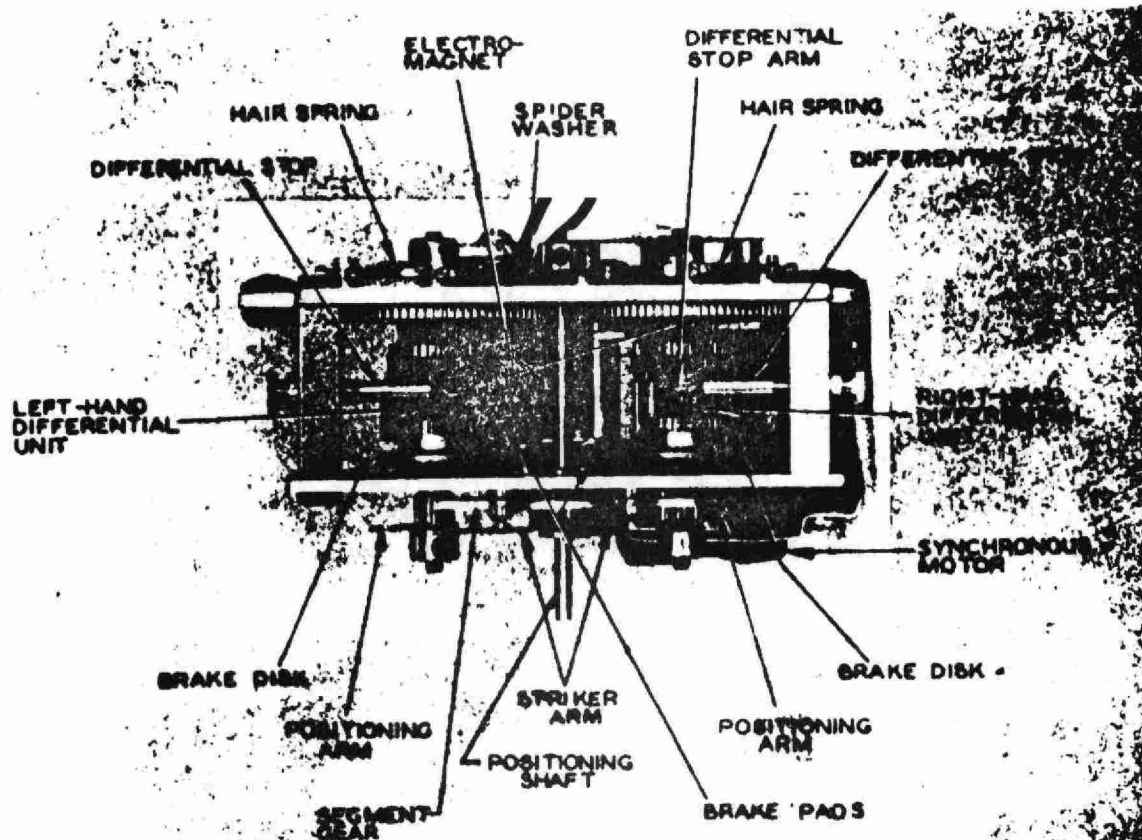
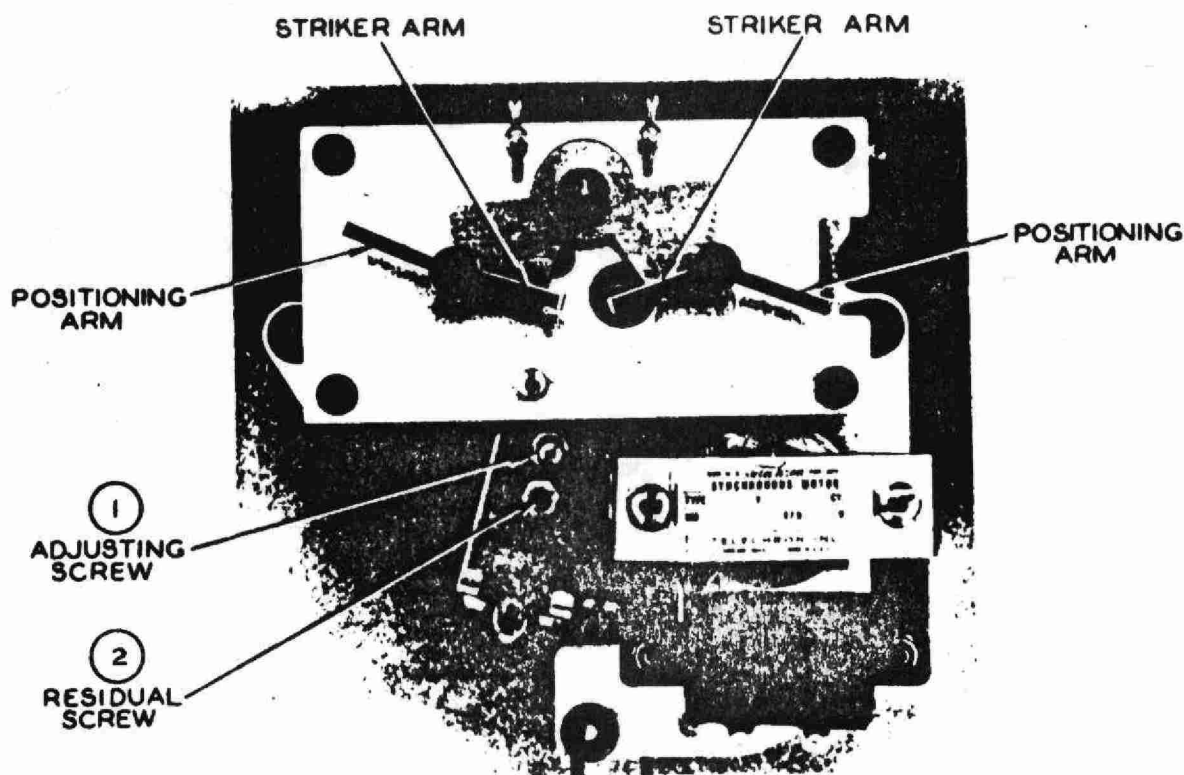


FIGURE 2. TYPICAL METAMETER TRANSMITTER WITH TIMER PLUG ATTACHMENT R14A AND SCALE PLATE REMOVED  
CODE TO FIGURE 2

- |  |                                      |
|--|--------------------------------------|
| 1. Locking Screw                           | 13. Span Adjustment for Cam Follower |
| 2. Bearing Screw                           | 14. Measuring Element                |
| 3. Lifter Plate                            | 15. Cam Follower                     |
| 4. Fixed Arm                               | 16. Mercury Switch                   |
| 5. Cam                                     | 17. Permanent Magnet                 |
| 6. Indicating Pointer                      | 18. Vane-Arm Assembly                |
| 7. Zero Adjustment for Cam Follower        | 19. Balance Cam                      |
| 8. Locking Screw                           | 20. Bearing Screw                    |
| 9. Span Adjustment for Indicating Pointer  | 21. Locking Screw                    |
| 10. Linearity Adjustment for Pointer       | 22. Trip-Plate Shaft                 |
| 11. Zero Adjustment for Indicating Pointer | 23. Convenient Outlet                |
| 12. Linearity Adjustment for Cam Follower  | 24. Timer Plug                       |
- Attachment R14A  
Optional

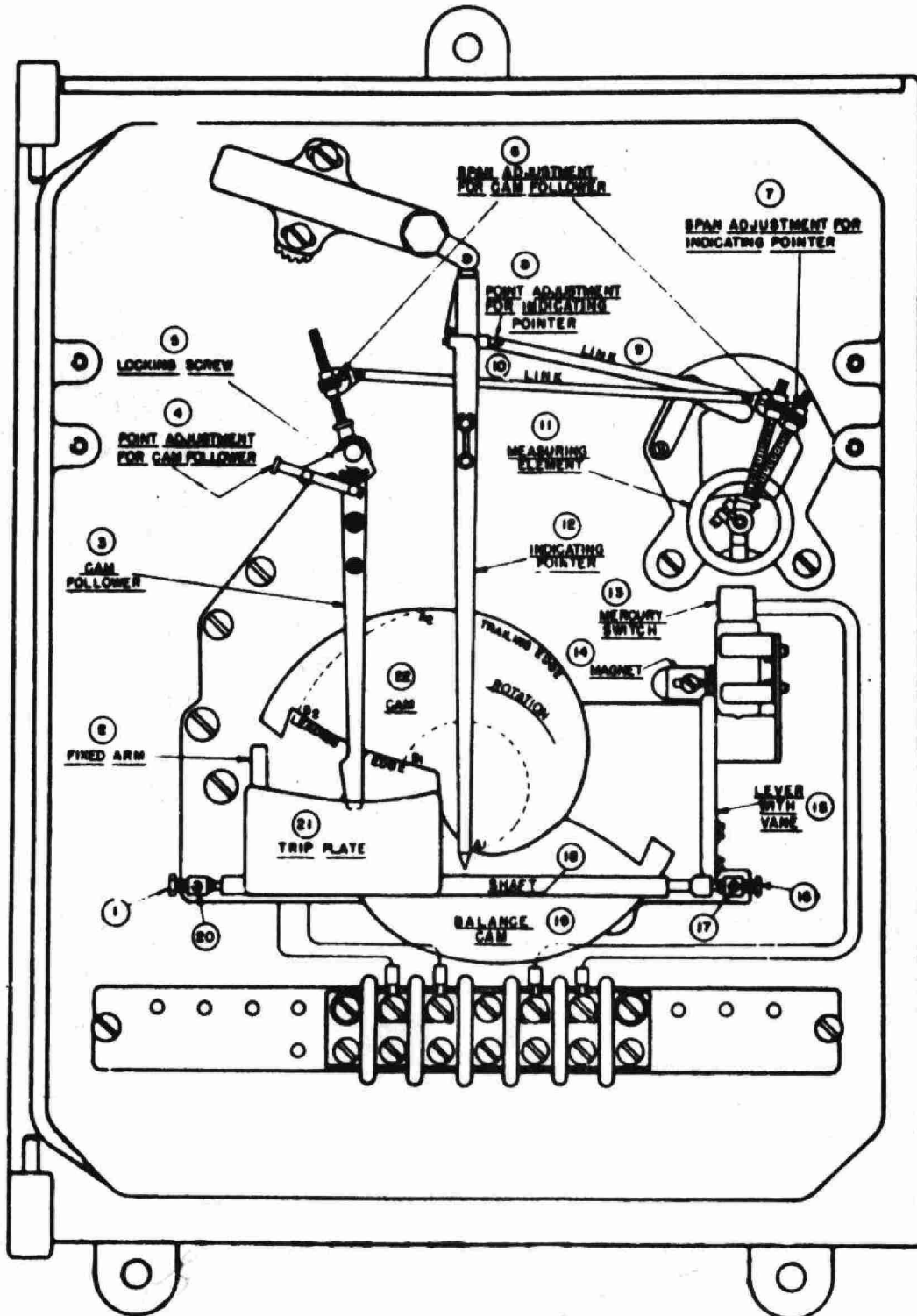


METAMETER RECEIVER MOVEMENT (TOP VIEW)



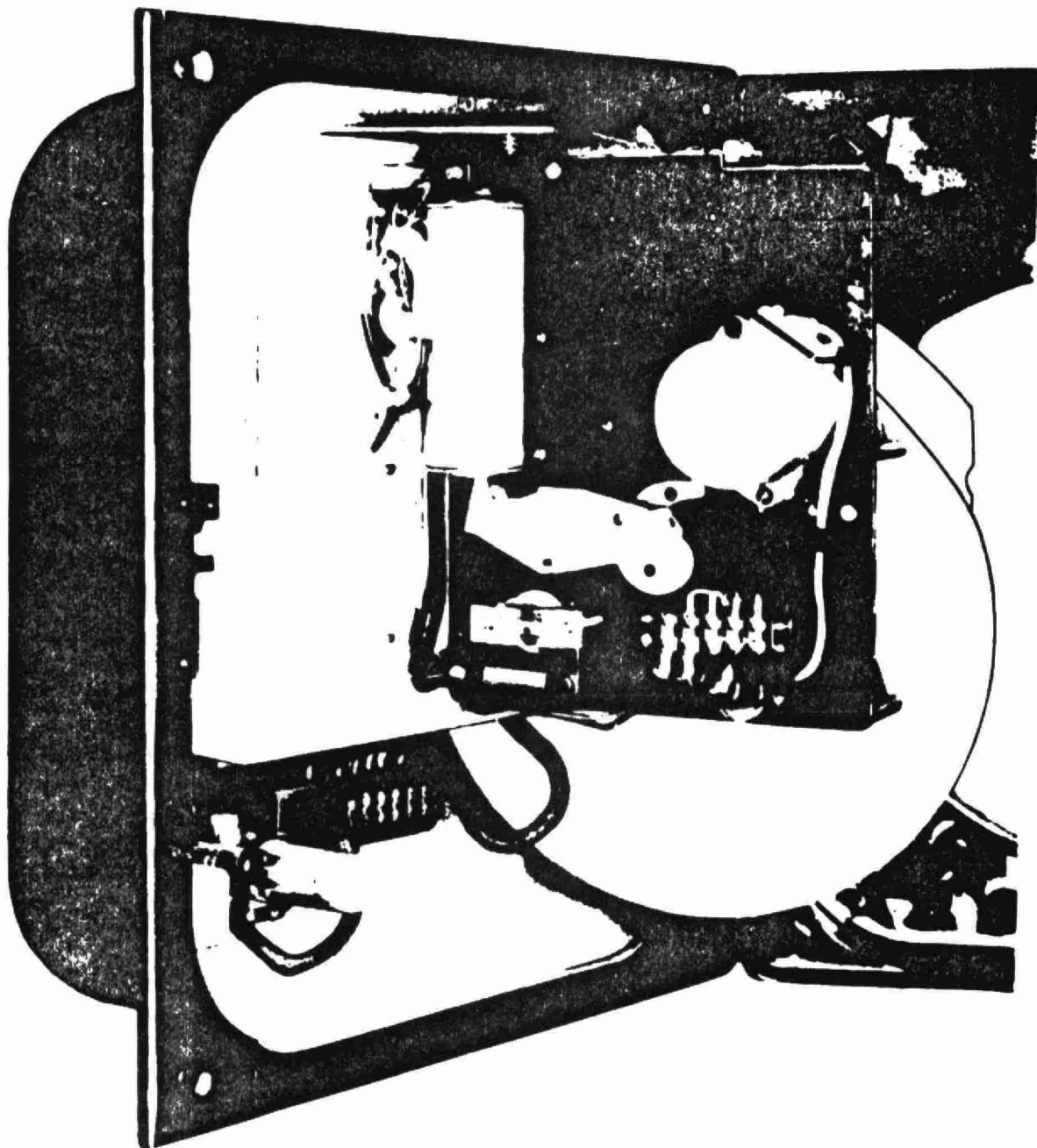
METAMETER RECEIVER MOVEMENT (FRONT VIEW)

# CAM TYPE TRANSMITTER





MAGNETIC CORE TYPE RECEIVER



PRELIMINARY AND PRIMARY TREATMENT

G. H. Mills, P. Eng.

Supervisor  
Design Approvals Branch

Preliminary treatment devices are used to protect pumping equipment and reduce some of the load on subsequent treatment units. They are designed to remove or cut-up the large suspended or floating solids, to remove the heavy inorganic solids and to remove excess amounts of greases and oils.

The following units are most commonly used in preliminary treatment:

1. Screens
2. Comminutors
3. Grit channels or chambers
4. Pre-aeration tanks

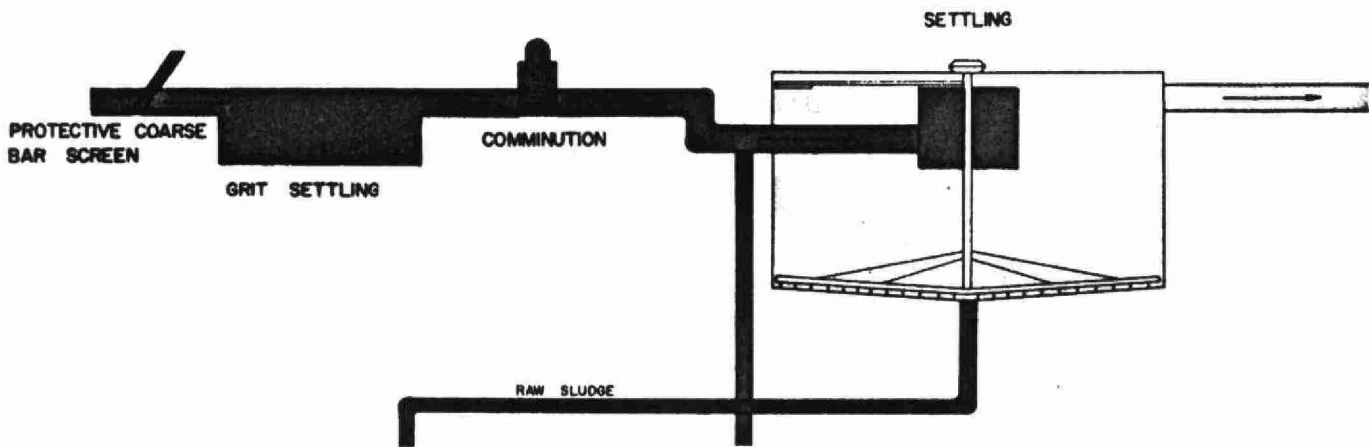
Primary treatment devices are used to separate or remove organic and inorganic settleable solids from the sewage by the physical process of settling or sedimentation. The following types of settling units are the most common:

1. Septic tank
2. Two-storey tank
3. Plain settling tank

PRELIMINARY TREATMENT

SCREENING

Screens were among the first devices used in attempts to remove potentially harmful solid material from sewage. The most common problem occurs in the form of rags, string, towels, sticks and large pieces of wood and garbage. Without screening, rags may pass through to the digester and wrap around the heating coils, resulting in a loss of heat transfer; blocks of wood can



Preliminary and Primary Treatment Units  
FIGURE 1

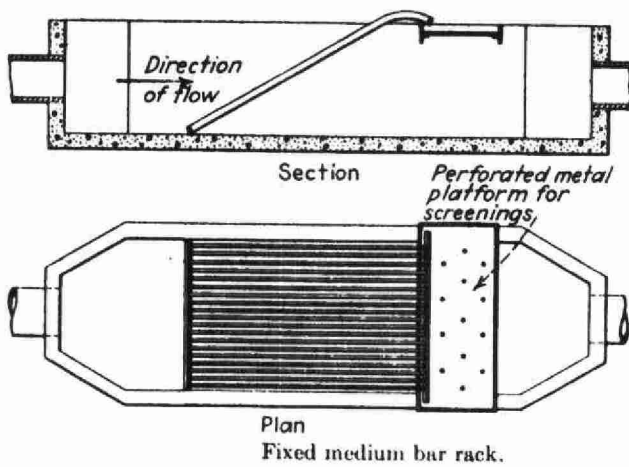


FIGURE 2

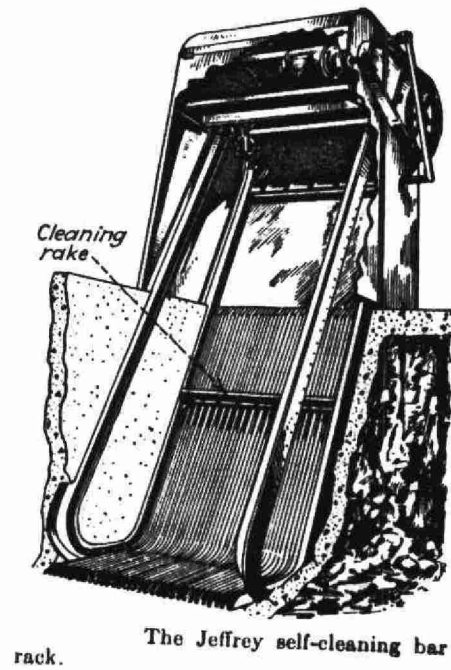
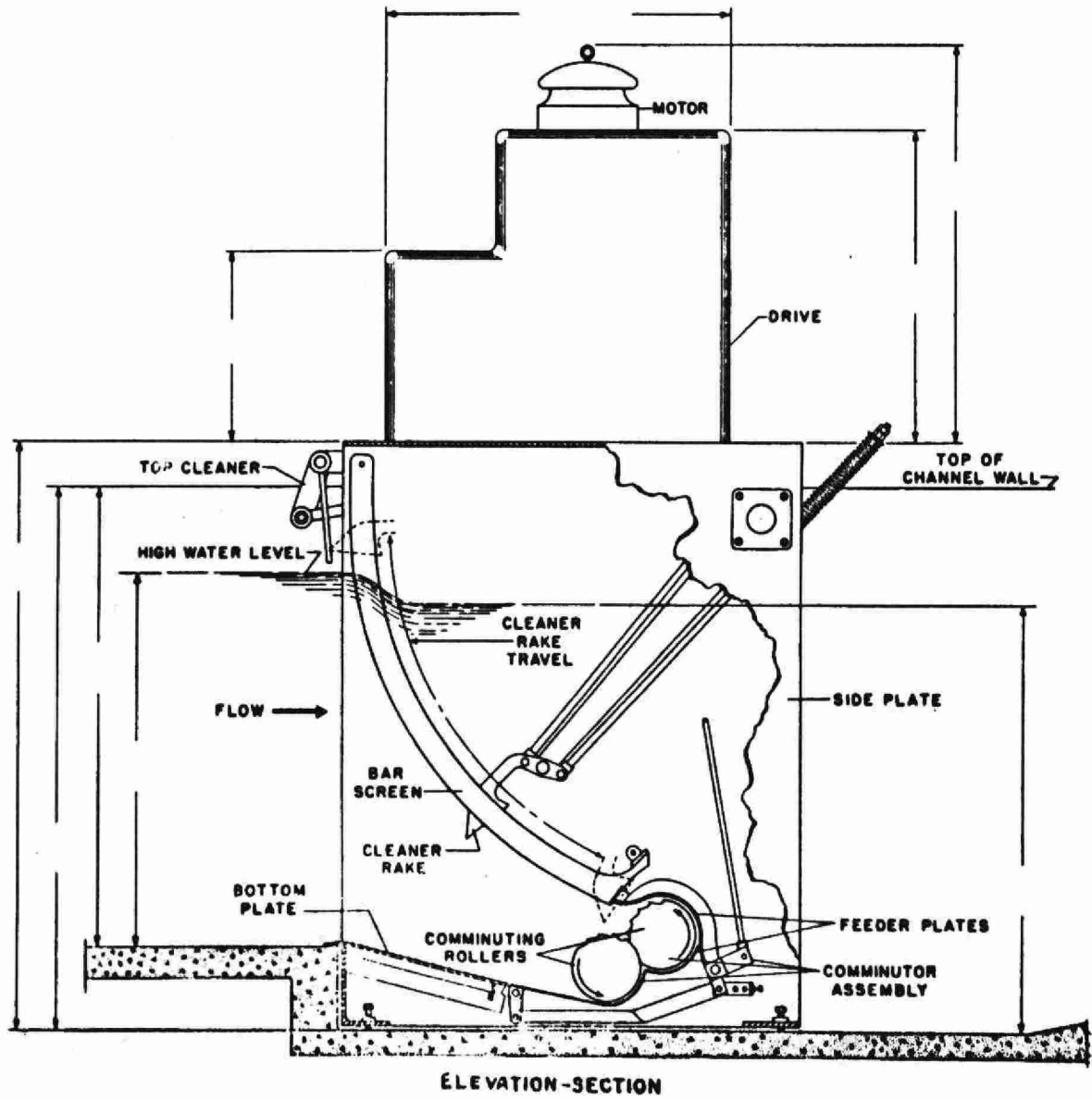


FIGURE 3



Mechanically Cleaned Bar Screen  
FIGURE 4

jam the sludge-collection equipment in the primary settling tank; and rags and string may become entangled in impellers of pumps and jam sprockets.

### (1) Coarse Screens or Racks

Coarse screens or racks are made of parallel bars with clear openings from 2 1/2 to 6 inches. The rack is usually set at an angle to the sewage flow for easier cleaning. These racks remove only large objects, such as wood, bricks or other floatables which may be washed into a combined sewer system. In such a system, these screens protect pumps and grit chambers which may be installed ahead of the regular bar screens or mechanical shredders.

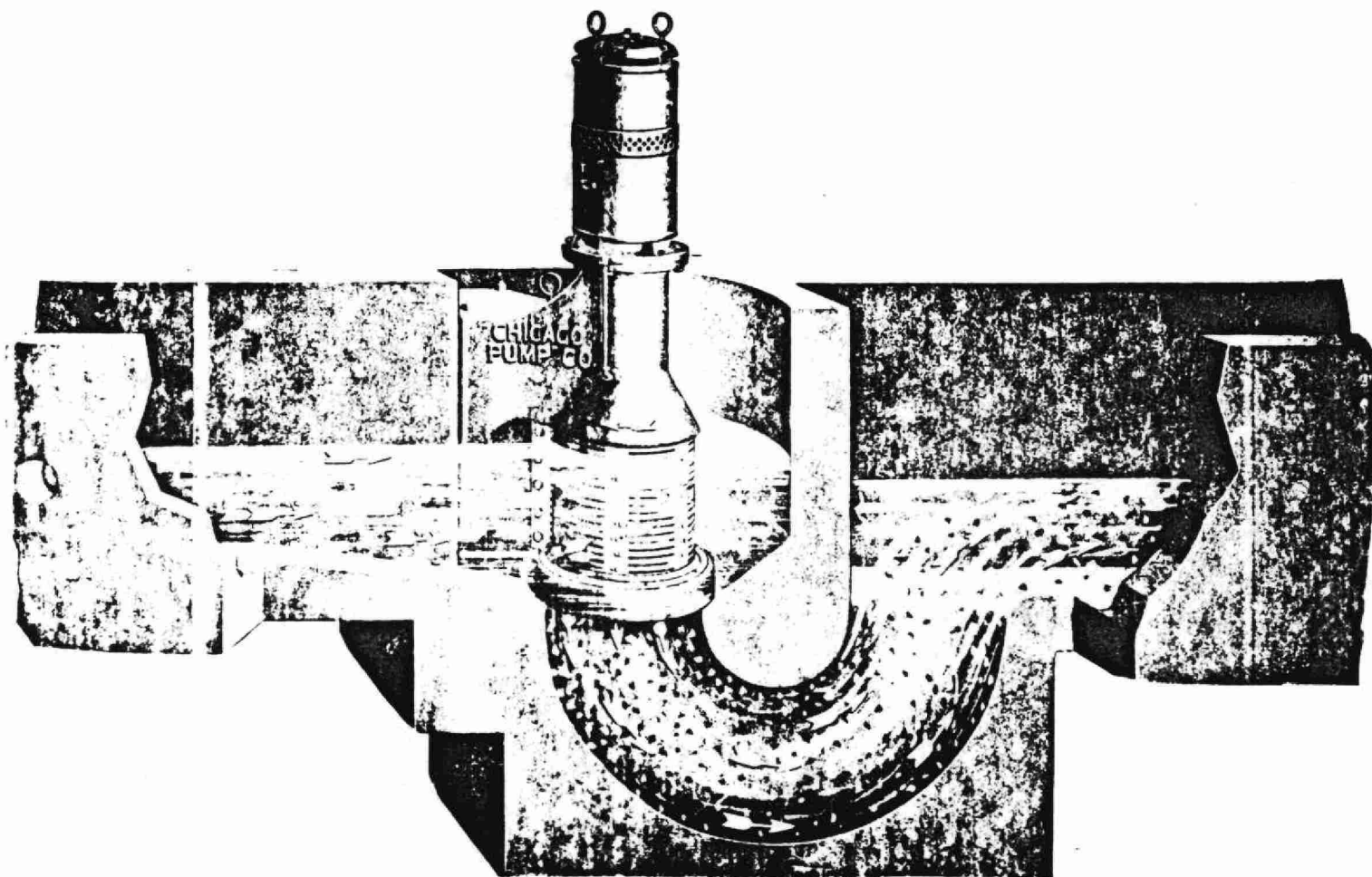
### (2) Bar Screens

Bar screens are installed in most plants as either the only unit for screening or as a standby for a comminuting device. See Figure 2. Although these screens are sometimes set vertically, they are normally sloped at 30 to 45 degrees to the vertical and terminate at a platform or basket onto which the screenings may be raked for dewatering. The clear openings between the bar may vary from 3/4 inch to 2 inches, with the most common being in the 1- to 2-inch range.

The velocity of flow through bar screens should be about 2 feet per second to prevent the settling of grit in the screen chamber and to prevent debris from being forced through the screen.

Bar screens may be either manually or mechanically cleaned units. The latter type have rakes (see figures 3 and 4) which periodically sweep the entire screen and they may be front cleaned or back cleaned, the latter not being subject to jamming at the bottom by deposits of trash. Mechanically cleaned devices have certain advantages in that they:

1. reduce labour costs
2. provide better flow conditions
3. produce less nuisance



Comminutor-Showing Cross-Section  
FIGURE 5

In some cases these devices are equipped with grinders which return macerated screenings to the sewage.

### (3) Fine Screens

Fine screens are mechanically cleaned devices using a medium of perforated plate, woven-wire cloth or very closely spaced bars. The openings are usually 3/16 inch or smaller. Fine screens should be preceded by a coarse screen or a shredder to remove the larger particles.

The band, disc and drum screens are the most common type of fine screens and are used principally in the larger plants where large quantities of screenings are collected. They are all of the moving type, and because of their ability to remove large volumes of material they require constant cleaning. In cases where the waste from a particular industry is causing difficulty, screens of this nature may be used at either the treatment plant or, more commonly, at the industry. Except for special cases they are no longer considered for sewage treatment because of the limited results obtained.

### (4) Comminuting Devices

A comminuting device is a mechanically cleaned screen which incorporates a mechanism that cuts the retained material without removing it from the sewage flow. See Figure 5. This tends to reduce odours, flies and unsightliness.

A comminutor is basically a vertically slotted drum screen submerged in the sewage flow. The drum may revolve against cutting members or the cutting members may oscillate against the drum. Travelling cutters are also used in conjunction with a bar screen, the cutters moving up and down on the bars cutting the debris as they move.

Comminuting devices are normally operated continuously, although if possible, the flow should be bypassed through a bar screen for a short period every few days to remove settled material, which tends to dull the cutting edges. Stones, sticks and other unwanted material should be removed from the upstream



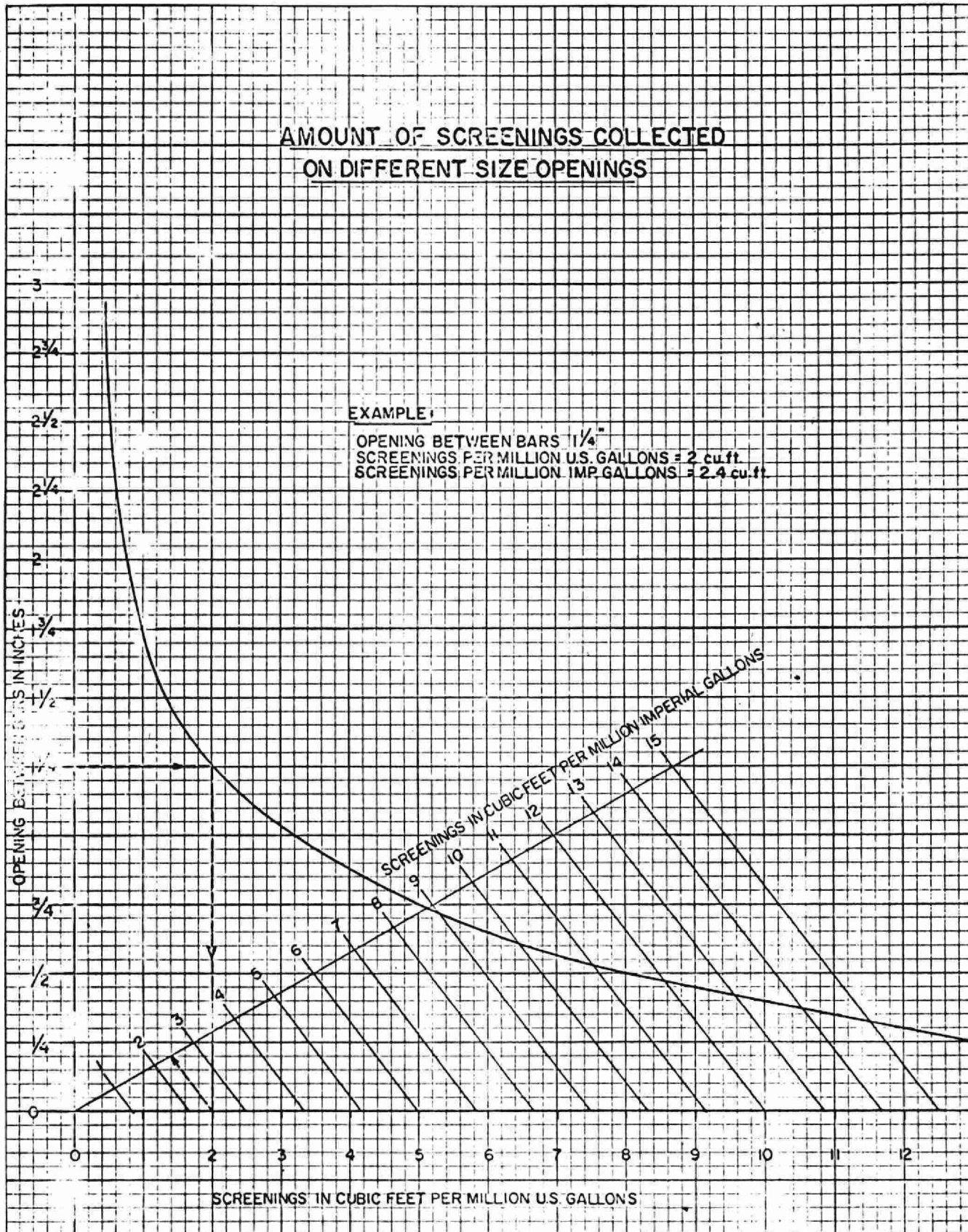


FIGURE 6



side when they are noticed. The unit should be hosed down daily.

### Cleaning of Screens

During dry-weather periods coarse trash racks should be cleaned daily and more frequently during storm flows.

Bar screens should be cleaned as often as necessary in order to prevent interference with a reasonably free flow, generally two to five times per day. Failure to clean the screens can result in one or more of the following:

1. Septic action upstream in the sewer
2. Surcharge of sewers
3. Shock loads on treatment units when they are finally cleaned

### Screenings

#### (1) Quantity

A coarse screen - 2 inches or larger openings - will usually collect about 1 cubic foot of solids per million gallons of sewage.

Medium screens - openings ranging from  $1/2$  to  $1\ 1/2$  inches - will ordinarily collect 5 to 15 cubic feet of material per million gallons of sewage. These screenings usually contain considerable organic material and have a moisture content of approximately 80 per cent and weigh 40 to 60 pounds per cubic foot.

Fine screens with openings of  $1/16$  to  $1/8$  inch will remove from 10 to 20 percent of the suspended solids.

Figure 6 shows representative volumes of screenings which can be expected from different-size bar screens. However, considerable variations from these figures occur and they cannot be explained by screen openings alone. Other factors affecting the quantity of screenings are the percentage of combined sewers in the system, the character of industrial wastes and the habits of the population served. It has been observed that the sewage

treatment plants serving penal institutions and mental hospitals have much greater than normal quantities of rags in the screenings.

## (2) Disposal

The disposal of screenings is a matter that should receive serious consideration since, even if they are thoroughly washed, they may become extremely obnoxious. Methods commonly employed include incineration, burial, drying with raw sludge and maceration and return to flow. The method used will generally depend on the type, size and location of the treatment plant.

Burial of screenings is the practice at most plants. The screenings should be buried in trenches and immediately covered with a layer of earth or washed grit. If the screenings are allowed to remain on drying platforms or in drying baskets for removal only one or two times a day, offensive odours can be prevented by sprinkling them liberally with powdered lime. The screenings should be buried sufficiently deep to avoid odours and flies and shallow enough to permit bacterial activity. A cover of 12 to 18 inches will probably give the best results.

At larger plants, the quantity of screenings is too large for burial at the plant site and the practice is to dispose of them at the municipal landfill site. If the screenings are to be removed from the plant for disposal, they should be deposited in covered cans either immediately after they are removed from the screens or after allowing a short period of dewatering. In the warmer months, to keep fly and odour problems to a minimum, the screenings should be washed down by hosing them on the drying platform.

Grinders are widely used for the disposal of screenings. The material is reduced in size and returned to the raw-sewage flow or mixed with sludge depending on the location of the grinders in relation to other treatment processes.

Material from the grinder either settles out in the primary settling tanks or are mixed directly with the raw sludge. The screenings become part of the raw sludge or primary scum introduced to the digester and are decomposed by the same action as the other solids. It is desirable, therefore, that the screenings be ground as fine as possible. Some digester foaming or excessive

scum blanket formation has been attributed to this method of disposal of screenings but proper scum control can overcome this problem.

Incineration of screenings has been found to be moderately satisfactory at some plants in the U.S. However, this method is not used in Ontario at present and most of the U.S. plants have abandoned it, except at the largest plants.

### GRIT REMOVAL

At one time it was believed that a separate sewer system did not warrant the need for grit-removal facilities. However, a considerable quantity of grit-type material is present in sewage because of industrial and domestic discharges and faulty sewer joints. Some grit enters through street drains, combined sewers or foundation drains. Where joints are poorly constructed, and the ground-water level is above the pipe, coarse sand may be admitted in substantial amounts.

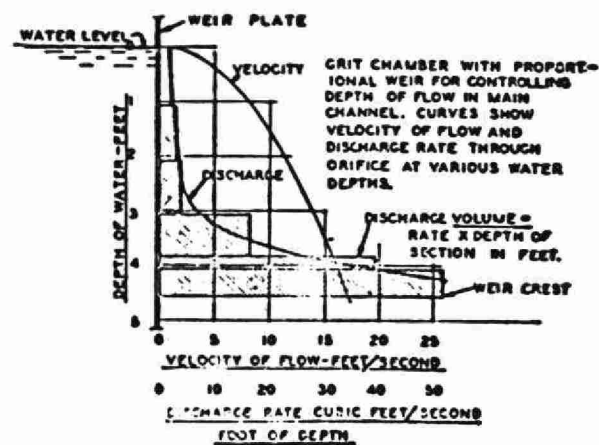
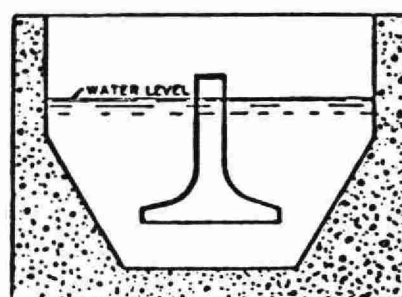
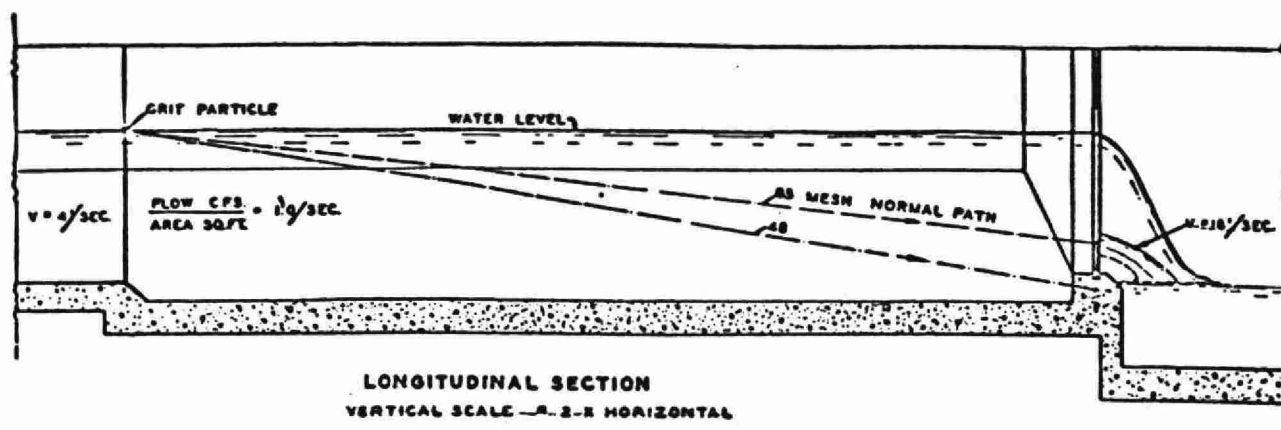
Grit removal prevents abrasive action on pump impellers and collector mechanisms, reduces clogging of pipes, tanks and hoppers, and eases sludge handling and disposal.

There are many types of grit removal units, but in reality there are basically two - manually cleaned and mechanically cleaned units. Manually cleaned units are used in smaller plants. Mechanical units are used where there are relatively high flows, large quantities of grit or the depth of the unit is too great for manual removal.

### Types of Units

There are three major categories into which removal facilities may be placed. There are:

- (1) grit channels
- (2) aerated grit chambers
- (3) mechanical devices



Rectangular Grit Channel  
FIGURE 7

(1) Grit Channel

The rectangular grit channel equipped with a proportional weir at the outlet end is the most common type of grit removal unit. Figure 7 shows this unit. The chamber is slightly larger in cross-section than the inlet sewer.

By reducing the flow from the usual 2 feet per second in the inlet sewer to 1 foot per second in the channel, the heavier, inorganic solids will be deposited, while the lighter organic solids will remain in suspension. The rate of flow is maintained at a more or less constant velocity by

- (1) gates
- (2) proportional weirs
- (3) flumes

The normal cleaning operation for manually cleaned units is as follows:

1. When grit accumulates to one-half of the liquid depth in the first half of the grit channel length, switch to clean channel
2. Dewater channel (if this is possible without washing out grit)
3. Remove grit after it is well dewatered
4. Measure and record quantity
5. Flush channel clean
6. Bury grit

It is not essential to remove water but if it is possible it lessens the work. If there is only one channel the problem is increased because of stirring and flushing to other parts of the plant. Generally, clean these at the lowest flow possible. A low velocity of flow is equally important at this time; therefore, close outlet end and increase depth.

In plants where only one mechanically cleaned channel is

provided, a manually cleaned unit may be employed as a bypass. Automatic or semi-automatic collectors are usually conventional conveyor-type equipment with buckets, plows, scrapers or rakes. A grit-washing or classification device may be included.

When mechanically cleaned grit chambers are in use, they should be cleaned at regular intervals to prevent undue loads on the cleaning mechanisms. Time-clock operation may be provided. It is difficult to say how often they should be operated, but continual operation is extremely rare.

## (2) Aerated Grit Chamber

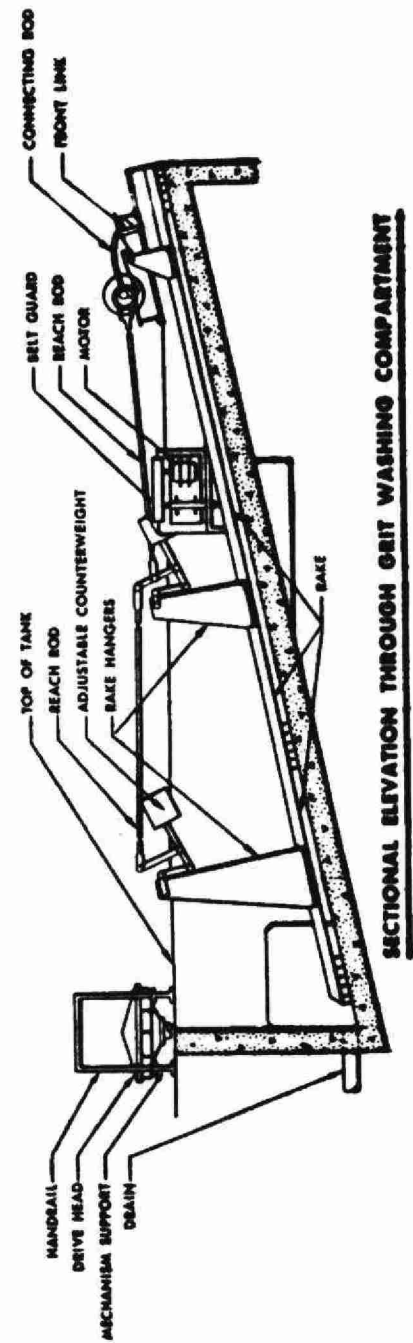
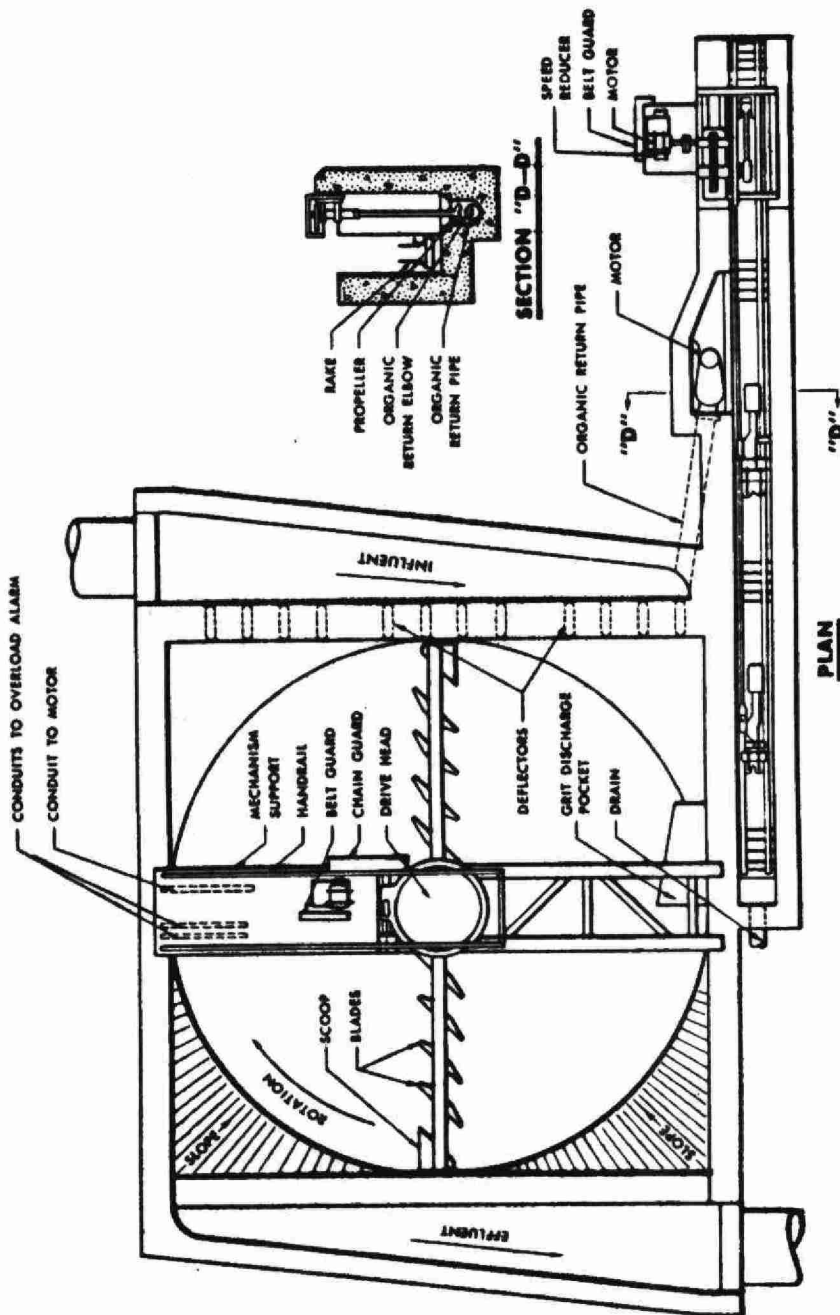
Grit can be made to settle in a spiral flow aeration tank and will accumulate beneath elevated air diffusers mounted along one of the longitudinal walls of the tank. The diffusers are mounted approximately 2 feet above the bottom. Hoppers are provided beneath the diffusers for collecting the grit. Flow enters the tank at the opposite end of the effluent weir and in a direction to coincide with the roll of tank contents. The heavier particles will settle to the bottom while the lighter, organic particles are carried with the roll and eventually discharged from the tank.

Flow velocities of 2 feet per second are developed in aeration tanks with air supplied at the rate of 3 cubic feet per minute per foot of tank length.

Removal of the accumulated grit from the hopper may be done by:

1. Clamshell bucket
2. Air-lift (if lift is not greater than 5 to 10 feet above liquid surface)
3. Jet pumps

One disadvantage to aerated grit removal is that it produces a clean grit. As grit yield goes this may be all right, but many operators also want to remove much of the cellulose and hair-like particles which, if not taken out with the grit, add to the digester inert scum layer. A detention tank is preferred in these cases.



Dorr Detritor  
FIGURE 8



### (3) Detritus Tank

Short-period sedimentation in a tank that operates at substantially constant levels produces a mixture of grit and organic solids called detritus. The lighter organic solids are subsequently removed from or washed out of the mixture.

Several manufacturers specializing in sewage disposal equipment have perfected this type of equipment. The Dorr Company has developed one such unit called the "Detritor" and this device is shown in Figure 8. It is noted that the detritor not only removes the grit but also washes it. A later section of this paper will deal with washing or classification devices.

The grit-collecting mechanism is installed in a square, shallow, concrete tank with filled-in sloping corners. Sewage enters along one side of the tank through adjustable vertical gates, which are set to provide a uniform influent velocity across the entire width of the unit. After entering, the sewage flows in straight lines across the tank and overflows at a weir constructed along the outlet side of the tank.

The collecting mechanism consists of two structural-steel arms, attached to a vertical shaft and fitted with outward raking blades with scoops on the ends. As the rakes revolve, settled grit is plowed outward to the radius where the end scoops collect and discharge it to a hopper at one side of the tank.

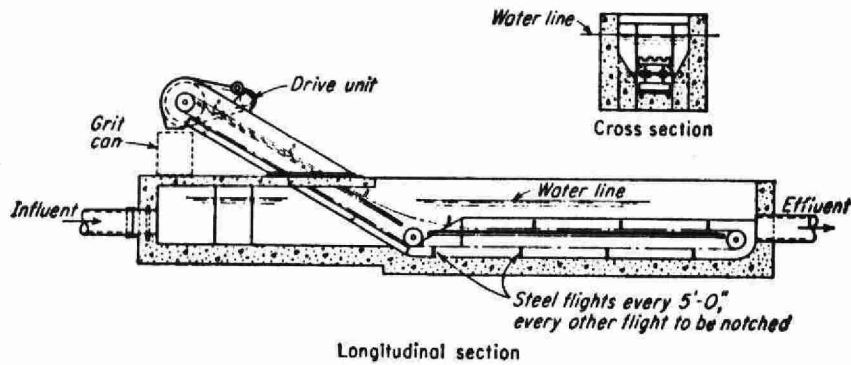
The grit is then discharged to a washing or classifying device.

#### Cleaning Grit

In order to obtain a relatively clean grit (less than 3% volatile matter) various methods of washing out the excess organic materials have been developed.

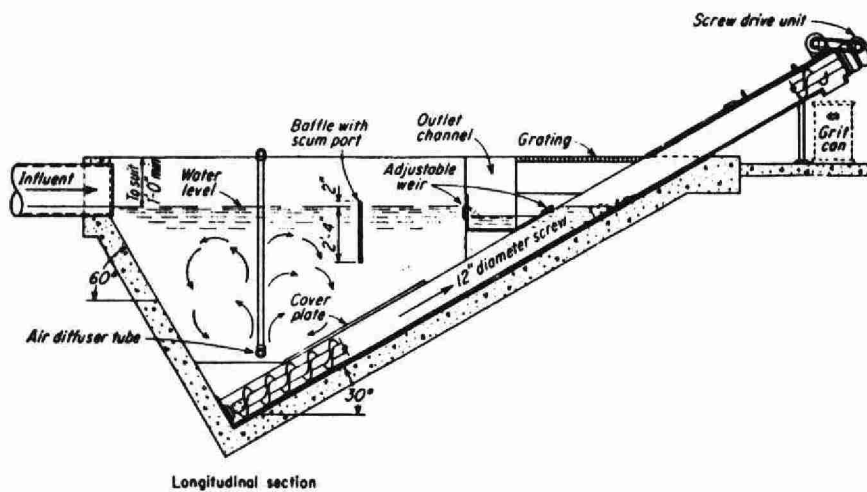
1. Elevation on a sloping ramp by means of a series of reciprocating rakes (refer to Figure 9). The reciprocating rakes convey the grit up the inclined tank and at the same time impart a rolling action which releases the entrained organic matter. The organics are pumped back to the influent end of the tank by a





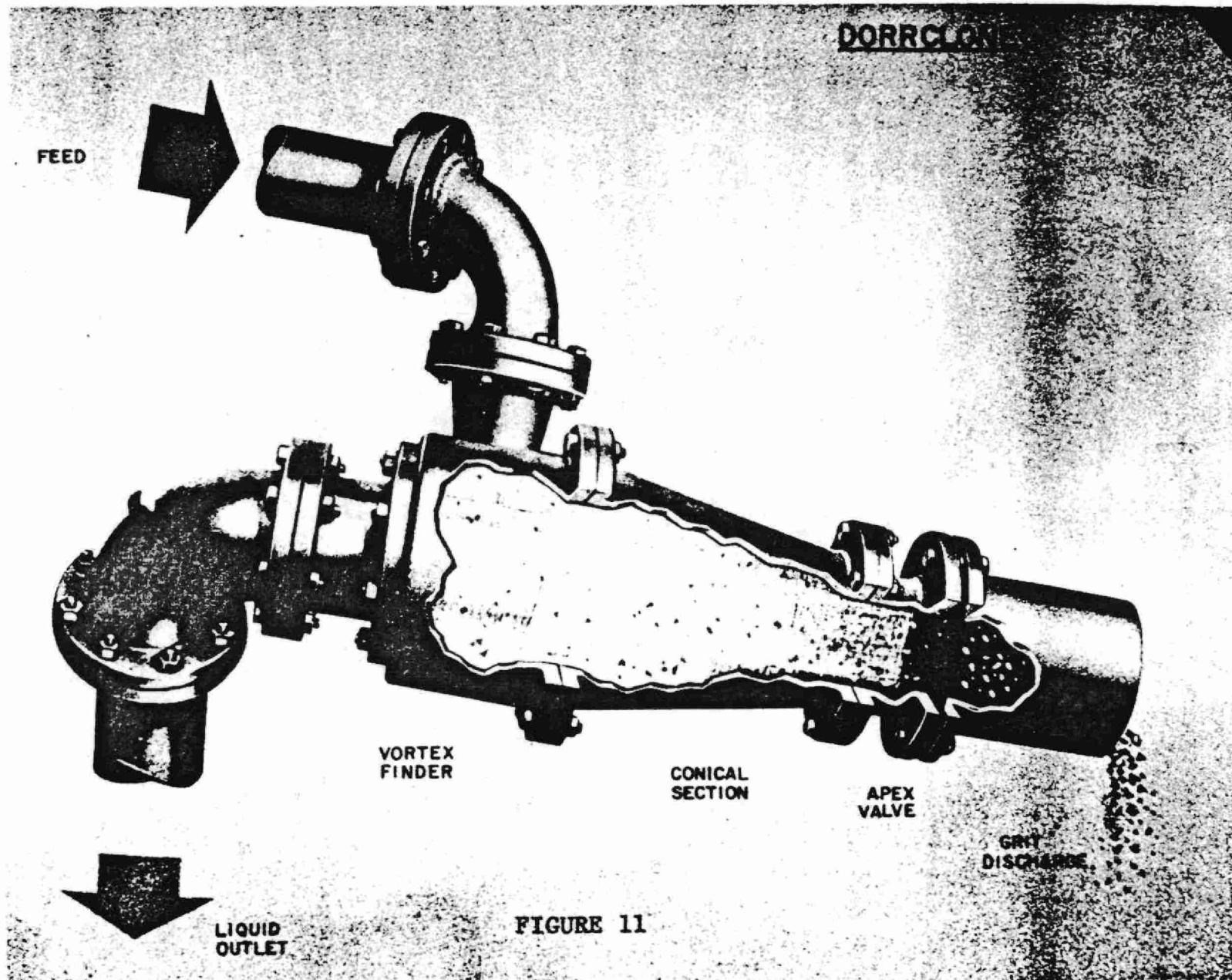
Mechanically Cleaned Grit Chamber  
(Jeffrey Manufacturing Co.)

FIGURE 9



Aerated Grit Chamber with Screw Conveyor  
(Link-Belt Co.)

FIGURE 10



pump which acts similarly to a propeller in a draft tube. Excess moisture drains off as the grit progresses up the latter part of the ramp.

2. Elevation by screw conveyor in a sloping trough. The action of this type of grit washer is basically the same as that described for the reciprocating-rake process. See Figure 10.

3. Aerated grit chambers -- the use of diffused air for grit removal as previously described produces a well "washed" or classified grit.

4. "Cyclone" classification units -- a diagram of one type (Dorr) of these units is shown in Figure 11. The slurry enters the cylindrical feed chamber tangentially and develops a cyclonic vortex pattern. Centrifugal forces throw the grit contained in the slurry to the walls of the cone. As these solids collect along the walls of the cone, they move towards the apex and discharge through the apex valve. The lighter, grit-free liquid moves to the inner spiral of the vortex where it is displaced into the overflow opening (vortex finder). Usually the flow from this type of unit is wetter than that of the reciprocating rake type unit; however, they remove grit up to a 150 mesh.

Under certain circumstances these units are used for the removal of grit from raw sewage.

#### Quantity of Grit

As in the case of screenings, it is not possible to state how much grit can be expected at each plant. Many variables affect the volume of grit. Average figures for the expected quantities of grit are 8 cubic feet per million gallons for combined-sewer systems and 3.5 cubic feet per million gallons for separate-sewer systems.

#### Disposal of Grit

Clean grit is characterized by the lack of odours which would normally result from the presence of decomposing organic matter. Except when grit is carefully washed, it will contain

up to 50 percent organic matter (mostly garbage) by weight. It is inevitable that some food value will be found in such grit and consequently it will become an attraction to insects and rodents as well as unsightly and odorous.

In the majority of cases, grit is disposed of by burial or at the municipal dump or landfill site. At the plant, unwashed grit which is removed from the removal facility should be kept in cans and should be removed to the disposal site at least daily. If the grit is adequately washed (less than 3% volatile) it may be used as fill around the plant or it may be used to re-sand sludge drying beds.

### Laboratory Control

The volume of grit removed should be recorded each time hand cleaned units are emptied. Daily records should be kept for mechanically operated units.

The percent volatile matter should be determined regularly where laboratory facilities are available. Tests should be made daily for mechanically cleaned units and for each batch removed in hand cleaned units.

Where laboratory facilities are not available at the plant, periodic samples may be submitted to the OWRC laboratory of the sewage entering and leaving the grit removal chamber. Volatile solids content of these samples will indicate to some extent the percent efficiency of the unit.

The grit may be nearly all organic or all inorganic.

No analysis gives a positive evaluation of the efficiency but if one test is done regularly changes will be indicated.

### Pre-Aeration

Aeration basins preceding or following screens and grit chambers aerate the raw sewage for one of more of the following purposes:

1. To remove gases from the sewage, especially hydrogen sulphide, which create odour problems, and also increase the chlorine demand of sewage. The release of gases and the addition of oxygen reduce odours in septic sewage. For effective results an aeration period of 30 minutes to several hours may be required.
2. To promote flotation of excessive grease, which then can be removed from the raw sewage at an early stage in its treatment.
3. To aid in the coagulation of the colloids (finely divided suspended solids) in the raw sewage for the purpose of obtaining a higher removal of suspended solids by primary settling.
4. Treatment of digester supernatant.

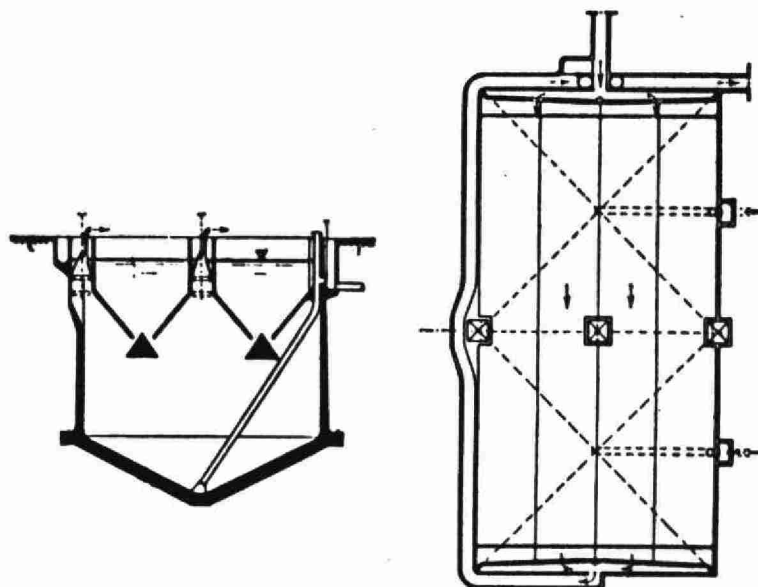
In general, pre-aeration tanks are designed for detentions of 5 to 15 minutes for grease removal, using 0.01 to 0.1 cubic foot of air per gallon of sewage treated. If flocculation of the fine suspended solids in the raw sewage is also attempted, the detention period must usually be extended to at least 15 to 60 minutes, the average time being about 30 minutes.

Aeration increases the skimmings or grease produced since the rising air bubbles attach themselves to heavier-than-water particles causing buoyancy. This buoyancy holds the grease particles in the surface flow. Some de-emulsifying of the grease also occurs which separates it from the sewage. The skimmings are removed several times a day by hand (at least twice) or by various makes of skimming devices, or they may be permitted to discharge to the primary settling tanks for removal.

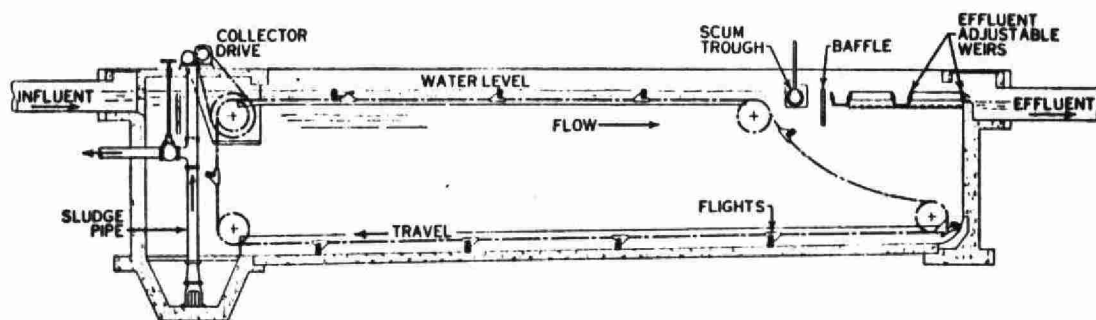
The sides of the basin should be hosed down daily and the skimming device should be hosed after each use.

#### PRIMARY TREATMENT

Primary sedimentation devices are designed to remove organic and inorganic settleable solids, by the physical process of settling. This is done by reducing the velocity of flow. In preliminary treatment this velocity is lowered from a velocity of 2 fps in the inlet sewer to about 1 foot per second for a very



Imhoff Tank  
FIGURE 12



Longitudinal section of a primary rectangular tank with Straightline sludge collector. Upper run of flights pushes scum to scum trough. Skimming is not provided in final tanks. Multiple effluent weirs provide a low overflow rate.

Rectangular Plain Settling Tank  
(Link-Belt Straightline)  
FIGURE 13

brief period during which the heavier inorganic solids are settled out as grit. In primary treatment the velocity of flow is reduced to a fraction of an inch per second in a settling or sedimentation tank for a sufficient length of time to allow the major portion of the settleable solids, which are largely organic, to settle out of the sewage flow. The effluent contains all dissolved organic wastes and the remaining suspended solids which are impractical to settle out.

There are a number of types of primary treatment devices or sedimentation tanks which are available and are in use.

### Septic Tanks

Septic tanks are designed to hold the sewage at a very low velocity under anaerobic conditions for a period of 12 to 24 hours, during which time a high removal of settleable solids is effected. Septic tanks are no longer used except for very small installations such as residences and schools.

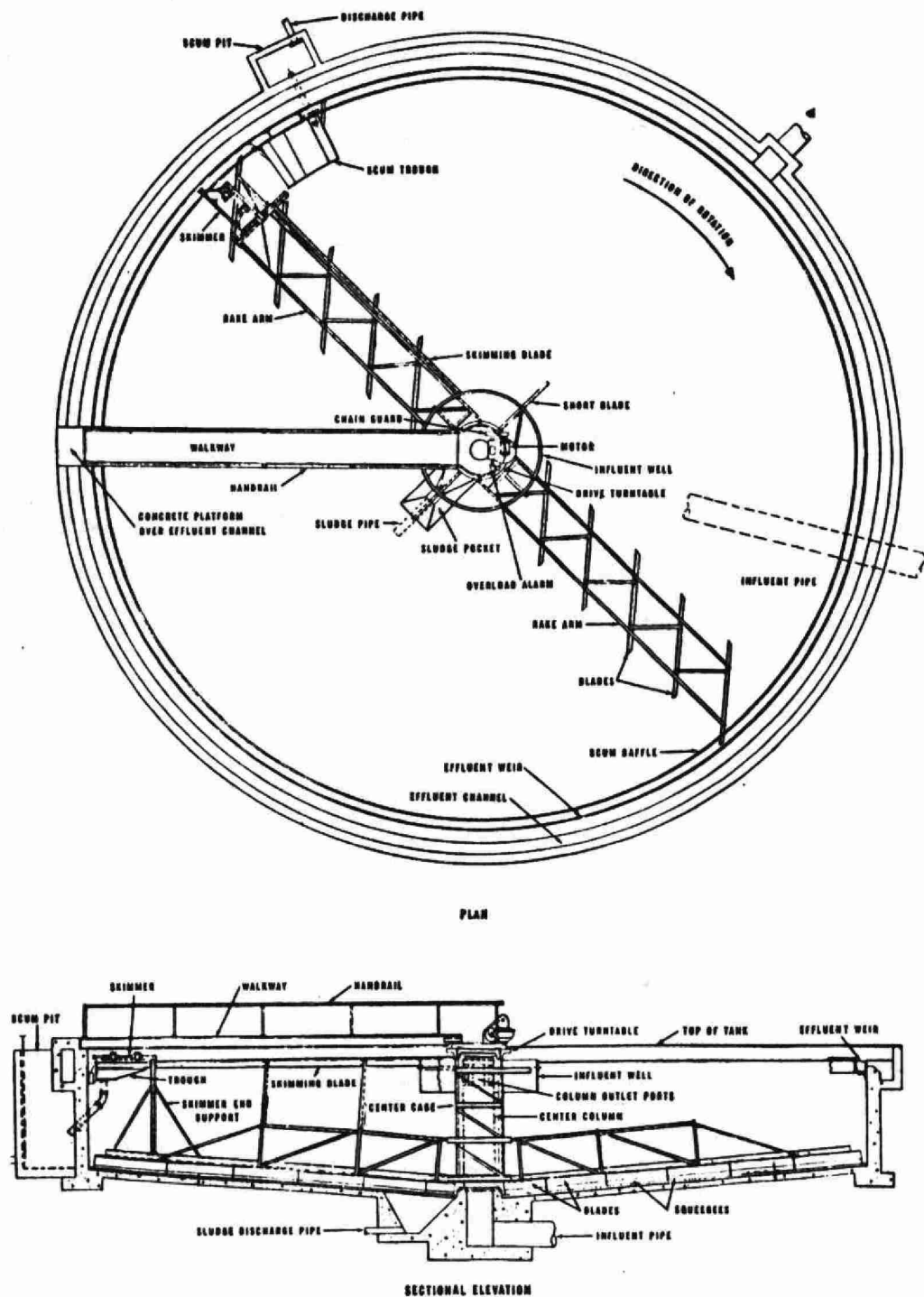
The length is usually 2 to 3 times the width in order to prevent short-circuiting and the accumulated sludge is removed two to three times per year by pumping or by ports in the bottom of the tank.

### Two-Storey Tanks (Imhoff Tank)

These units are no longer built because they are expensive to construct due to different framework and excessive depths (30 ft. +). Retention periods vary from 1 1/2 to 4 hours, depending on the type of additional treatment. See Figure 12.

The following should be considered with respect to operation.

- (a) Daily removal of grease, scum, and floating solids from the sedimentation compartment.
- (b) Weekly scraping of sides and sloping bottom.
- (c) Monthly reversal of flow (if possible).



Circular Plain Settling Tank  
(Dorr Type S-7)  
FIGURE 14



- (d) Control of scum in scum chamber - break and if depth exceeds 2 feet it should be removed.
- (e) Removal of sludge before depth approaches 18 inches of slot.

### Plain Settling Tanks - Mechanically Cleaned

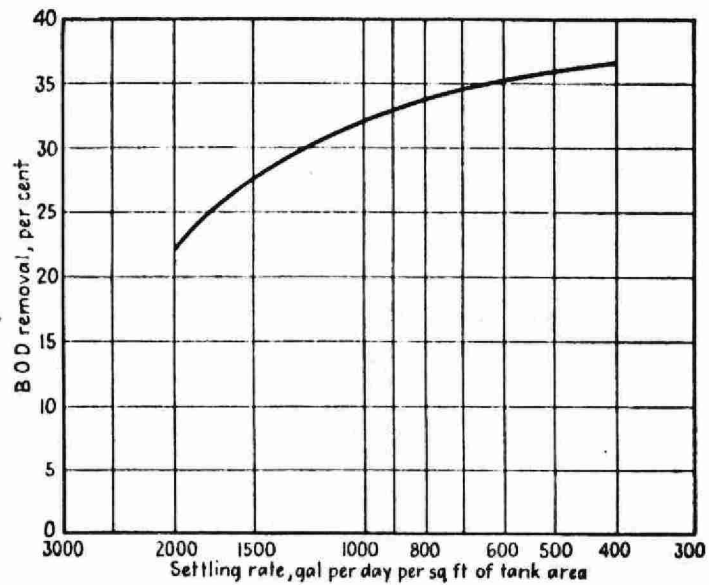
These tanks may be rectangular, circular or square, but all operate on the same principle of collecting the settled solids by slow-moving scrapers to a point of removal. See Figure 13.

The settled solids are taken from the tank continuously or at frequent intervals so that decomposition with gas formation does not have time to develop. The solids are then handled by other units which will be discussed in other lectures in the series.

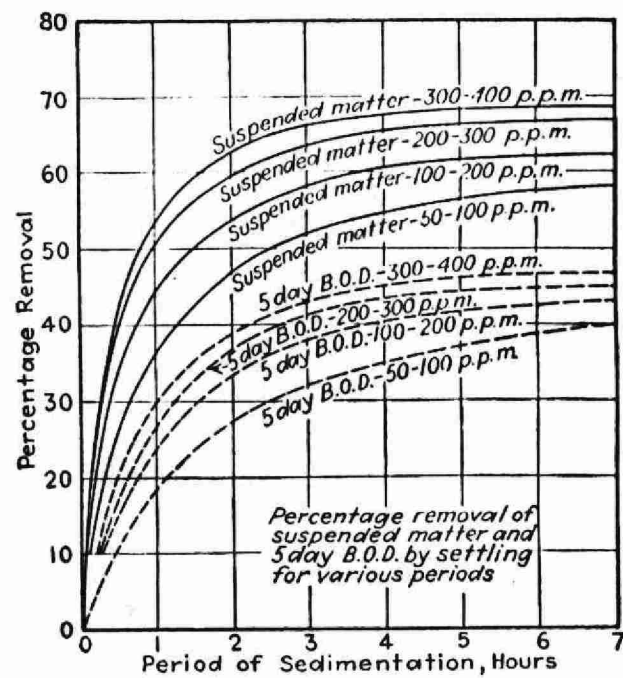
In the rectangular tanks the scrapers are attached near their ends to two endless chains with pass-over motor-driven sprockets. The scrapers are dragged slowly along the tank floor pushing the settling solids to the sludge hopper located at the inlet end of the tank. The scrapers are then lifted by the chains to the surface of the tank they serve to push floating solids, grease and oil to a scum collector at the outlet end of the tank. Another type of mechanism consists of a travelling bridge spanning the tank from which is suspended a blade to push solids to the point of removal and a skimmer blade for floating solids, grease and oil. These blades operate when travelling in one direction and idle when travelling in the return direction.

The circular sedimentation tanks have scraper arms attached to a central motor driven shaft. The bottom of the tanks are sloped towards the centre and the scrapers move the settled solids to a sludge hopper at the centre. Skimmer arms are attached to the central shaft at the surface for collection of floating solids, greases and oils. See Figure 14.

In the square tanks the mechanism is similar to that in the circular tanks. The major difference is that one or both of the rigid arms of the mechanism are equipped with pivoted corner blades which reach out into the four corners of the tank



Overflow Rates and BOD Removal  
FIGURE 15



Period of Sedimentation and BOD  
and Suspended Solids Removal  
FIGURE 16

and remove the solids in these areas to the path of the circular mechanism.

### Design of Plain Settling Tanks

#### Inlets

Inlets should be designed to dissipate the inlet velocity, diffuse the flow equally across the entire cross section of the tank and prevent short-circuiting. They may be of the weir type but are commonly a channel with spaced port openings.

#### Baffles

These are placed at the inlet, to diffuse flow, and at the outlet ends of the tank, to hold back floating solids. Mechanically cleaned tanks usually have a scum trough, which serves as the outlet baffle.

#### Outlet Weirs

Outlet weirs are designed to remove the settled sewage as a thin sheet from the surface of the tank. They are usually adjustable. It is important that they be kept level. The term "weir loading" is used to express the gallons per day passing over 1 foot of the weir. In plants less than 1 mgd capacity this should not exceed 10,000 gallons per linear foot per day but may be up to 15,000 for larger plants.

#### Surface Settling Rate

This is expressed in terms of gallons per square foot of tank area based on the daily sewage flow. The rate should not exceed 600 gallons per square foot per day for plants less than 1 mgd but may be in the range of 900 to 1,200 for larger plants. This rate is an important factor and is directly related to the percent removal of BOD and suspended solids. See Figure 15.

### Detention Period

This is simply the length of time the sewage is held in the tank based on the sewage flow and tank volume, assuming uniform flow and total displacement. It was once used as the sole basis for tank design but has since been replaced by weir loading and surface settling rate. The detention period should be at least 2 hours. See Figure 16.

### Efficiency

About 40 to 60 percent of the total suspended solids can be expected in plain settling tanks. The BOD should be reduced by about 25 to 35 percent. Such figures are general and cannot, of course, be applied to specific cases. The efficiencies of removal for various sewage strengths are shown on Figure 16.

### Operation of Mechanically Cleaned Tanks

The establishment and maintenance of proper time schedules for operation of the mechanical cleaning equipment and for the removal of sludge from the tank are the most important factors in tank operation. They must be determined for each plant.

In general, circular-tank sludge collecting mechanisms are operated over longer periods than rectangular-tank collectors. Mechanical sludge collectors in the circular tanks are often run continuously, whereas with rectangular tanks the collectors may only be operated from 3 to 12 hours per day. They should be run often enough to prevent a build-up of solids on the tank bottom. If the solids are allowed to build up in the tank, an undue load may be placed on the mechanism at start-up and cause damage to the equipment. Also, the tank volume is reduced resulting in a lower retention period. Solids may also be decomposed with the resultant production of gas in the settling tank and some floating sludge. Before sludge is removed from the tank the mechanism should be run for a sufficient time to assure satisfactory collection of bottom solids in a sludge hopper.

General operations should include daily cleaning of all vertical and inclined walls and the removal of all material from

baffles.

Frequent determinations of the sludge level should be carried out to ensure removal prior to decomposition. Gas bubbles and floating sludge are definite indications of decomposition.

### Sludge Withdrawal

The aim in raw sludge withdrawal is to secure as dense a sludge as possible, preferably in the range of 5 to 7 percent total solids, and to clear the settling tank hoppers as thoroughly as possible without drawing liquid. Sludge may be removed by hydrostatic pressure in smaller installations or by pumping. The manner in which sludge is removed has a great effect on both the settling tank and the digester.

### Raw Sludge Sampling

Raw sludge volumes often vary considerably from day to day. Consequently, to control pumping periods properly, at least one good method of raw sludge sampling is needed at every plant. Any of the following may be employed:

1. Visible outlets, including discharge pipes above the maximum liquid level to raw sludge concentration tanks, or to a control box adjacent to the roof of the sludge digestion tank, have been installed.
2. A sight glass provided by one manufacturer can be inserted in the discharge pipe from the sludge pumps.
3. A sampling tap located either near the raw sludge pumps or in a sludge digestion tank gallery is frequently provided.
4. Many operators use a sampling device on the discharge side of the sludge pumps for observation of the pumped sludge. This method is advantageous where long sludge discharge lines are used.

As a general guide, if a sample of sludge in a test jar

after settling for 10 minutes shows more than 50 percent volume of sludge, pumping should be continued. If it shows less than 50 percent, removal may be considered reasonably complete.

It is generally better to remove sludge three to four times a day and provide a more constant food supply to the organisms doing the work rather than to remove all of the daily sludge accumulated at one time. If too little sludge is removed the clarifier effluent will deteriorate. If too much is removed the digester operation will deteriorate and extra supernatant must be treated.

#### Scum Removal

Removal of scum, floating garbage, and grease is universally recognized for efficient operation of settling tanks. A scum barrier or baffle is generally provided somewhere in the flow path, between the centre of the tank and the effluent weir. Excessive skimming will result in too much water being carried out with the scum, while insufficient skimming will permit scum to flow around or under the baffle and from the tank effluent. Scum must be removed daily and ideally small amounts should be removed continuously.

#### Chemical Precipitation

This is a modified sedimentation process where a coagulant is employed to improve the efficiency of settling. Chemicals used are alum, ferric chloride, lime, etc. Proper mixing is essential and the dosages will vary with the sewage. The process is not popular due to cost and volume of sludge produced. Efficiencies of 80-90% removal of suspended solids and 50-55% removal of BOD are common.

## SAFETY PRACTICES IN SEWAGE WORKS

R. J. Norton

Safety and Training Officer

### INTRODUCTION

The dangers associated with sewage works operation emphasize the need for safety practices. Physical injuries and body infections are a continuous threat and occur with regularity. Explosions and asphyxiations from gases or oxygen deficiency occur at sewage plants and during sewer maintenance and although infrequent at any particular location, on a country-wide basis many such accidents occur. These occupational hazards may be largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many and carelessness all too frequently prevails until an accident results. Then it is too late.

It is the responsibility of sewage works supervisors to acquaint themselves with the hazards associated with plant maintenance and operation and to take steps to avoid them. Accident prevention is the result of thoughtfulness and the application of a few basic principles and knowledge of the hazards involved. It has been said that the "A, B, C" of accident prevention is "always be careful". However, one must learn how to be careful and what to avoid. With this knowledge one can then always think and practice safety.

### HAZARDS

The overall dangers of accidents are much the same whether in manholes, pumping stations or treatment plants. These hazards may be as follows:

1. Body infections
2. Physical injuries
3. Dangers from noxious gases or vapours and oxygen deficiencies.

NO. 1 Body Infections

This hazard to plant personnel although very real and ever present can be largely reduced by the operator himself by following a few basic rules of personal hygiene. A few of these self applied rules are as follows:

1. Never eat your lunch or put anything into your mouth without first washing your hands.
2. Refrain from smoking while working in open tanks, on pumps, or cleaning out grit channels etc. Remember you inhale or ingest the filth that collects on the cigarette from dirty hands. Save your smoking time for lunch hours or at home.
3. A good policy is "never put your hands above your collar when working on plant equipment".
4. Always wear your rubber boots when working in tanks, washing down etc., don't wear your street shoes.
5. Don't wear your rubber boots or coveralls in your car or at home.
6. Always wear rubber or plastic coated gloves when cleaning out pumps, handling hoses etc.
7. Don't just wash your hands before going home, wash your face too, there is as much of your face to carry germs as there is of your hands.
8. Wear a hat when working around sludge tanks, cleaning out grit and other channels, don't go home with your head resembling a mop that just wiped up the floor around a cleaned out pump.
9. Keep your finger nails cut short and clean, they are excellent carrying places for dirt and germs.



Workers who come into contact with sewage are exposed to all the hazards of water-borne diseases, including Typhoid Fever, Amorbic Dysentery, Infectious Jaundice and other intestinal infections. Tetanus and skin infections must also be guarded against.

A majority of infections reach the body by way of the mouth, nose, eyes and ears. Therefore, washing your hands is a must before eating or smoking. Wear protection gloves where possible.

Soap preparations requiring no water rinse are available for field use. The common drinking cup should be banned, each man should have and use his own.

Typhoid and Tetanus inoculations are recommended. These may be obtained free of charge from local Health Officers.

#### Wearing Apparel

Rubber or rubberized cotton gloves, rubber boots and coveralls are designed for body protection against dampness and contact with dirt, wear them at all times when working in tanks etc.

Rubberized or rain suits can be worn in very wet or dirty places and can be washed off with a hose and brush, the same as rubber boots.

Hard hats should be available and worn when working below ground level, i/e in open tanks etc., or in confined areas with low head room or during any construction on the plant site. Always wear safety goggles when grinding, chipping or scrapping and wire brushing old painted surfaces.

#### PHYSICAL INJURIES - First Aid

Except for minor injuries, wounds should be treated by a doctor and reported for possible Workman's Compensation. Service truck and plants should have first aid kits and as many of the plant personnel as possible should have "St. Johns Ambulance" first aid instruction.

It is a "Compensation Board" regulation that any plant having (5) five or more people working as a group on any shift one of them is required to hold a "St. Johns Ambulance Certificate" in first aid. Remember, no cut or scratch is too minor to receive attention.

### NOXIOUS GASES, VAPOURS ETC.

A noxious gas or vapour is one that is directly or indirectly injurious or destructive to the health and life of a human being.

They can cause explosions, asphyxiation and some are poisonous. Non-poisonous gases can asphyxiate by displacing or excluding existing oxygen in confined areas.

How is a noxious gas detected in an area? and what type of gas or gases would it likely be?

First, let us talk about entering a sewer manhole or any confined space that contains or has contained sewage that carry organic compounds or a tank where sludge is or has been stored.

Before entering these places it is necessary to test the air in the place to see if it is safe for men to enter for any reason or length of time. The person doing the testing shall be known as the testor.

In shallow manholes or tanks the air can be tested by lowering the probe of a gas sniffer through the holes in the manhole covers or through the open manhole of the tank.

In deeper manholes and tanks say of 10 ft. to 20 ft. deep or very large tanks it would be necessary to go down into the tank or manhole to get proper readings.

The testor then would be required to wear self-contained breathing apparatus and a safety harness and rope, while testing the air conditions in the manhole or tank.

Does a negative reading on the dial of the gas sniffer indicate that it is safe for entry without breathing equipment? The answer is, not necessarily. If the area being tested is small or has only the one opening the air should be sampled for oxygen content.

Supposing the testor has a reading of .5% on his dial, this is well below the (L. E. L.) lower explosive limits of any gas. Does this reading indicate safe conditions? Again no, because the gas being recorded on the sniffer gauge could be Hydrogen Sulfide ( $H_2S$ ) and this gas is not only highly explosive but is very poisonous.

Let us say the testor has a high reading on his sniffer dial of 20% or more of gas to air by volume this is above the explosive limits (U. E. L.) of methane gas, a gas commonly found in such places, but it does indicate a low oxygen content.

The man or men designated to test a confined area for air conditions and safe entry should also be provided with an oxygen deficiency meter that records the actual percent of oxygen present, any reading of less than 16% of oxygen would indicate that the confined area is unsafe for entry.

The testor should also be equipped with a "Drager" meter to enable him to determine the type of any gas present.

We have discussed the method and types of meters required to test a confined area for possible air contamination by gases or vapours that can be found in such places, so now lets talk about the various gases and vapours and their effect on a man without proper protection.

A list of the types of gases that are commonly found in sewers, deep manholes and covered sludge holding tanks and digesters are: - Hydrogen Sulfide  $H_2S$ ; Carbon Dioxide  $CO_2$ ; Carbon Monoxide  $CO$ ; Methane  $CH_4$ ; and in lesser percentages Hydrogen  $H_2$ ; Nitrogen  $N_2$  and in the case of sewers there are times when gasoline, paint thinners, solvents and fuel oil are encountered.

Refer to chart No. 1 "Characteristics of dangerous gases" Item "A" Hydrogen Sulfide  $H_2S$ .

Hydrogen Sulfide gas has been placed first among other dangerous gases as it must be considered as the most all around dangerous gas to be found anywhere in a W. P. C. P. sewer or pumping station, and it is the gas most likely to be encountered in any of these places as it is a product of decomposition of organic matter in the sewage.

The maximum safe 8 hour exposure % by volume in air was set at 0.002% or 20 ppm but in recent years the U. S. Bureau of Mines lowered the safe 8 hour exposure to 0.001% or 10 ppm the 60 minute safe exposure has correspondingly been lowered by 0.02% to 0.01%.

Don't depend on detecting the presence of  $H_2S$  gas by smelling a "rotten egg" odour as it can be mixed with other gases that will diffuse the smell.

As per chart No. 1, exposure of 2 to 15 minutes at 0.01% impairs sense of smell. As the percentage increases, the ability to notice it by smell is completely lost.

Remember these figures, 0.01% impairs sense of smell, 0.07% to 0.1% rapidly causes acute poisoning, death in a few minutes at 0.2% or 2000 ppm.

The poisonous aspects of  $H_2S$  Hydrogen Sulfide is due mainly from the sulphur content of the gas, but since it has an equal amount of Hydrogen it is also highly explosive.

Its explosive range as per chart No. 1 is 4.3 (L. E. L.) to 46.0 (U. E. L.) as compared to Methane or natural gas at 5.0 (L. E. L.) to 15 (U. E. L.).

Notice that the most likely location of highest concentration is listed as near the bottom of a well, sewer etc., except, when the air is warm and humid, in other words on a hot humid summer day the gas could be encountered half way down or even at the top of a manhole or wet well. (Specific Gravity 1.19) = air at 1.0)

$H_2S$  gas has another disagreeable characteristic besides being poisonous and explosive and that is corrosive.  $H_2S$  gas when saturated with moisture and in the presence of air, forms Sulphuric Acid that deteriorates cement, steel, brass gate valves and iron ladder rungs. The fumes from the presence of  $H_2S$  in the air will cause certain type of house paints to become streaked with a blackish grey colour, it will also turn bath-room sinks and tubs a dirty grey colour.

**WARNING** Do not, under any circumstances, enter any manhole, wet or dry well, or any confined space where there is any possibility of the presence of  $H_2S$  gas, while wearing a canister type respirator.

A canister respirator will not protect you in heavy concentrations of  $H_2S$  gas or any other type of harmful gases or oxygen deficiency conditions.

(ITEM B) on the chart is Carbon Monoxide  $CO$ , it is lighter than air (0.97) = air at 1.0) 60 min. safe exposure 0.04%, 8 hr. safe exposure 0.01%, (L. E. L.) 12.5 (U. E. L.) 74.0; unconscious in 30 min. at 0.2%, fatal in 4 hours at 0.1%.

(ITEM C) Carbon Dioxide  $CO_2$  heavier than air (1.53) = air at 1.0) non-explosive, usually found with Methane in digester gas.

(ITEM D) Methane  $\text{CH}_4$  Gravity (0.55) = air at 1.0) explosive range 5% (L. E. L.) to 15% (U. E. L.) volume to air mainly produced in a digester used as fuel for W. P. C. P. boilers B. T. U. Rating between 500 B. T. U. to 750 B. T. U. as compared to natural gas rated at 1000 B. T. U. per. cu. ft.

The other gases listed on No. 1 chart are to be found in manholes, sewers, and wet wells and must be guarded against for explosions and oxygen deficiencies they may cause.

As already stated, do not enter into any confined space where the air conditions are unknown without first, testing the air and never while wearing a canister type respirator, even if the air conditions are known.

Chlorine is not listed on this chart, it is listed later under the heading of "Chlorine".

In the foregoing pages it has been stated that an area or confined space suspected of containing dangerous gases is checked out by a person referred to as a testor and the equipment he must use is listed. But who is this person?

Section 12 subsection 1-5 Industrial Safety Act. 1964, Department of Labour explains.

Section 12-(1) - No confined space referred to in this section shall be tested by any person other than a competent person.

(a) Designated by the employer.

12 (2) Every employer shall ensure that any tank, vat, chamber, pit, pipe, flue or other confined space that may be entered by any person.

(a) has a suitable manhole or other means of easy egress from all accessible parts of the confined space;

and

(b) is safe for entry.

12 (3) Where gases, vapours, mists, fumes or dusts that are likely to be dangerous to a person are present in any of the confined spaces referred to in subsection 2, or there is in the confined space a deficiency of oxygen or a temperature that is likely to be dangerous to a person, the employer shall ensure that no person enters the space unless,

(a) every practicable step has been taken to remove from the confined space such gases, vapours, mists, fumes or dusts;

- (b) effective steps have been taken to prevent entry into the confined space of additional quantities of such gases, vapours, mists, fumes or dusts;
- (c) the confined space has been competently tested and found safe for entry without the use of a breathing apparatus; and
- (d) ventilation adequate for the safety of any person therein is provided.

12 (4) Where any of the confined spaces referred to in subsection 2 has been tested and found;

- (a) unsafe for entry; or
- (b) safe for entry but may thereafter become unsafe to remain in or enter unless the person is using a suitable breathing apparatus, the employer shall ensure that no person enters or remains in such confined space unless,
- (c) the person is using a suitable breathing apparatus and a safety harness or other similar equipment to which is securely attached a rope, the free end of which is held by a person equipped with a suitable alarm who is keeping watch outside the confined space and who is capable of pulling such person from the confined space;
- (d) the safety harness, rope and other equipment mentioned in clause C is periodically inspected by the employer and is maintained in good working order at all times;
- (e) there is conveniently available a person adequately trained in artificial respiration; and
- (f) the person is using such other equipment necessary to ensure his safety.

12 (5) Where a confined space has been tested and found safe for entry for a specified time but may thereafter become unsafe unless a person is using a suitable breathing apparatus, the employer shall ensure that any person who enters the space without using a suitable breathing apparatus.

- (a) leaves the space at the end of the specified time; and
- (b) does not re-enter or remain in the space except in compliance with clauses c, d, e, and f of subsection 4.

12 (6) Where any confined space contains any dangerous liquid or solid or is at a temperature that endangers the safety of any person, the employer shall ensure that no person enters or remains in the space unless he is using equipment or device that will ensure his safety.

SUMMARY OF SUBSECTION ONE and TWO

Subregulation 12 (1) covers the requirement that tests shall be done by a "competent person." This is not a defined term in the sense that it outlines standards by which competency can be judged but rather states:

- (a) He shall be designated by the employer,  
Present "competent persons" are,
  - 1. Safety Officer
  - 2. Assistant Safety Officer
  - 3. Plant Superintendent
- (b) His name shall be recorded on the premises and it shall be at all times available to the inspector.

Subregulation 12 (2) covers the employer's obligation to:

- (a) provide means of access
- (b) ensure safety for entry.

A confined space is safe for entry by either:

- (a) Inherent design so that the confined space is safe to enter.
- (b) Test that the confined space is safe to enter, or
- (c) Rendering the confined space safe to enter and confirming the fact by tests.

The entering of confined spaces such as sewers, man-holes etc., and the regulations governing their safe entrance as defined by the Department of Labour has been discussed, but this lecture would not be complete without discussing the one big cleanout that occurs every six to eight years in plants having digesters.

## DIGESTERS

At the appointed time for a complete cleanout, the following procedure is to be followed:

1. Brief all personnel involved in this work on the type of gases present, the hazards that must be considered at all times, the safety precautions to be taken and the safety equipment to be used.
2. Have on plant site all equipment required to assist in the work.
3. Methods of Procedure

NOTE: Great care must be taken from the start of this work that all sources of ignition are guarded against, e.g., sparks from tools, use or moving of equipment, smoking, wearing shoes with metal clips on the heels, etc., and leather soled shoes that are worn sufficiently to expose the shoe nails.

All personnel working on the roof shall wear rubber boots or rubber soled shoes.

All matches, cigarettes, and lighters shall be left in the men's lockers.

Smoking shall not be permitted on the ground in the area of the digester.

Non-sparking tools should be used when possible.

- a) Release the stored gas pressure in the digester slowly by holding the pressure relief valve slightly open until all pressure has been expelled.

Do not lift this weighted valve off completely until all the pressure is expelled, then lift it off and leave it off.

- b) Remove all man-hole covers and leave off.
- c) Start removing the contents of the digester.
- d) When the man-hole covers have been removed, record explosion meter readings at the man-holes as the contents are removed.



- (e) When the contents have been lowered to a point where the explosion meter readings are below the L. E. L. (Lower explosive limits) the sludge level in the digester should be around six feet below the level of the roof.

The foregoing instruction was for fixed roofs only.

Digesters having any type of floating roof the contents would have to be removed until the roof was lowered firmly onto its corbels then the same procedure would be followed as per a fixed roof. Do not release the stored gas under a gas holding floating roof until it is resting on the corbels.

#### DIGESTER AND COVERED SLUDGE HOLDING TANKS

##### Material required for complete cleanout.

Non-sparking tools

Exhaust fans (2) explosion proof motors.

Safety harness (parachute type)

Man-hoist or "A" frame with pulley, 700 to 900 lb. lift.

Steel cable, 60 ft. min. length, 1000 lb. test, (1/8"-3/16")

Two sets of flood lights

Aluminum extension ladder, 40 ft.

If compressed air is required to break up the scum blanket or concentration of settled sludge a compressor of 80 psi and at least two outlets will be required. Two lengths of galvanized pipe one 20 ft; one 12-15 ft; fittings and couplings for conversion from air hose to pipe.

All electrical equipment must be explosion proof of an approved design.

Loud sounding device must also be on hand for emergency, (Data sheet 8-14 para. 12, Department of Labour)

A self contained breathing unit of 30 min. duration.

A man in attendance with first aid and rescue training.

Note: Using Compressed Air

Compressed air can be used to dislodge and smash up thick solids in the digester.

It is far more effective than using a water hose as it homogenizes the sludge into the existing water.

Under normal conditions it is unnecessary to add any water to the contents until the tank is half empty.

The air is discharged into the digester usually through two 3/4" or 1" galvanized pipe connected to the end of the air hose.

One pipe of some 20 ft. is positioned approximately 5 ft. in front of the sludge draw-off pipe in the bottom of the tank.

The second pipe of 10 ft. to 15 ft. is used as a probe to smash up scum formations on the surface and to churn up the contents generally.

When the contents have been lowered below the half-way mark and is heavy, care must be taken that too much sludge is not moved into the draw-off sump at one time.

A water hose will also be required from this point on.

Warning

At all times when compressed air is being used in a digester, explosive mixtures of gas and air are being produced, particularly during the initial stages of sludge removal.

After the contents have been lowered 8 to 10 ft. and the air has been used constantly, the gas that was entrapped in the sludge has been released and the hazard of explosive mixtures reduced. However, when the air is again discharged into any amount of sludge after being shut off for any length of time the ratio of gas and air can be in the explosive range for a time depending on the amount of sludge present.

During the use of an air hose a greenish vapour sometimes appears at the point of air discharge into the sludge. When this occurs remove the air pipe to another location or shut off air supply until this vapour vents off.

Do not generate this vapour any more than is necessary.

Many operators have used compressed air for sludge removal and, for breaking up scum formations, without any trouble.

The hazards must be known and all safety precautions taken during the operation.

Digesters and the immediate area around them must be considered as a hazardous area at all times.

The posting of plainly visible signs should be mandatory in a plant.

"DANGER NO SMOKING" or "OPEN FLAME" signs are required at Entrance to digester control buildings.

Digester roofs.

Ladders leading to the roof.

Digester gas compressor roofs.

Sludge truck loading pipes.

Sludge discharge pipes at drying beds.

The safety precautions, operating procedure for clean-out and safety equipment and signs recommended for digesters must also be used when cleaning out covered sludge storage tanks.

Open sludge storage tanks can also be dangerous especially during final stages of clean-out by men working in the bottom of the tank.

## CHARACTERISTICS OF DANGEROUS GASES ENCOUNTERED IN SEWERS, SEWAGE PUMPING STATIONS AND SEWAGE TREATMENT PLANTS

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR=1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER UPPER LIMIT LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
CARBON DIOXIDE	CO <sub>2</sub>	COLORLESS, ODORLESS WHEN BREATHED IN LARGE QUANTITIES MAY CAUSE ACID TASTE. NONFLAMMABLE. NOT GENERALLY PRESENT IN DANGEROUS AMOUNTS UNLESS AN OXYGEN DEFICIENCY EXISTS.	1.53	CANNOT BE ENDURED AT 10% MORE THAN FEW MIN, EVEN IF SUBJECT IS AT REST AND OXYGEN CONTENT NORMAL. ACTS ON RESPIRATORY NERVES.	4 TO 6	0.5	- -	AT BOTTOM; WHEN HEATED MAY STRATIFY AT POINTS ABOVE BOTTOM	PRODUCTS OF COMBUSTION, SEWER GAS, SLUDGE. ALSO ISSUES FROM CARBONACEOUS STRATA.
CARBON MONOXIDE	CO	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE, POISONOUS.	0.97	COMBINES WITH HEMOGLOBIN OF BLOOD. UNCONSCIOUSNESS IN 30 MIN AT 0.2 TO 0.25%. FATAL IN 4 HR AT 0.1%. HEADACHE IN FEW HR AT 0.02%.	0.04	0.01	12.5 70.0	NEAR TOP, ESPECIALLY IF PRESENT WITH ILLUMINATING GAS.	MANUFACTURED GAS, FLUE GAS, PRODUCTS OF COMBUSTION, MOTOR EXHAUST, FIRES OF ALMOST ANY KIND.
GASOLINE	C <sub>5</sub> H <sub>12</sub> TO C <sub>9</sub> H <sub>20</sub>	COLORLESS, ODOR NOTICEABLE AT 0.03%. FLAMMABLE.	3.0 TO 4.0	ANESTHETIC EFFECTS WHEN INHALED. RAPIDLY FATAL AT 2.4%. DANGEROUS FOR SHORT EXPOSURE AT 1.1 TO 2.2%.	0.4 TO 0.7	0.10	1.3 6.0	AT BOTTOM	SERVICE STATIONS, GARAGES, STORAGE TANKS, AND HOUSES.
HYDROGEN	H <sub>2</sub>	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE.	0.07	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	-	-	4.0 74.0	AT TOP.	MANUFACTURED GAS, SLUDGE DIGESTION TANK GAS, ELECTROLYSIS OF WATER. RARELY FROM ROCK STRATA.

\* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

CHART NO. 1

## CHARACTERISTICS OF DANGEROUS GASES (CONTD.)

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR=1)	PHYSIOLOGICAL EFFECT*	MAX SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR) LOWER UPPER LIMIT LIMIT	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
HYDROGEN SULFIDE	H <sub>2</sub> S	ROTTEN EGG ODOR IN SMALL CONC. EXPOSURE FOR 2 TO 5 MIN AT 0.01% IMPAIRS SENSE OF SMELL. ODOR NOT EVIDENT AT HIGH CONC. COLORLESS. FLAMMABLE.	1.19	IMPAIRS SENSE OF SMELL RAPIDLY AS CONC. INCREASES. DEATH IN FEW MIN AT 0.2% EXPOSURE TO 0.07 TO 0.1% RAPIDLY CAUSES ACUTE POISONING. PARALYZES RESPIRATORY CENTER.	0.02 TO 0.03	0.002	4.3 46.0	NEAR BOTTOM, BUT MAY BE ABOVE BOTTOM IF AIR IS HEATED AND HIGHLY HUMID.	COAL GAS, PETROLEUM SEWER GAS. FUMES FROM BLASTING UNDER SOME CONDITIONS SLUDGE GAS.
METHANE	CH <sub>4</sub>	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.55	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	PROBABLY NO LIMIT PROVIDED OXYGEN PERCENTAGE IS SUFFICIENT FOR LIFE.		5.0 15.0	AT TOP, INCREASING TO CERTAIN DEPTH.	NATURAL GAS, SLUDGE GAS. MANUFACTURED GAS, SEWER GAS. STRATA OF SEDIMENTARY ORIGIN. IN SWAMPS OR MARSHES.
NITROGEN	N <sub>2</sub>	COLORLESS, TASTELESS, NONFLAMMABLE. PRINCIPAL CONSTITUENT OF AIR (ABOUT 79%).	0.97	PHYSIOLOGICALLY INERT.	-	-	- -	NEAR TOP, BUT MAY BE FOUND NEAR BOTTOM.	SEWER GAS, SLUDGE GAS. ALSO ISSUES FROM SOME ROCK STRATA.
OXYGEN (IN AIR)	O <sub>2</sub>	COLORLESS, ODORLESS,	1.11	NORMAL AIR CONTAINS 20.93% OF O <sub>2</sub> . MAN CAN TOLERATE DOWN TO 12% MIN SAFE 8-HR EXPOSURE, 14 TO 16%. BELOW 10% DANGEROUS TO LIFE. BELOW 5 TO 7% PROBABLY FATAL.	-	-	- -	VARIABLE AT DIFFERENT LEVELS.	OXYGEN DEPLETION FROM POOR VENTILATION AND ABSORPTION, OR CHEMICAL CONSUMPTION OF OXYGEN.
SLUDGE GAS	-	MAY BE PRACTICALLY ODORLESS, COLORLESS.	VARIABLE	WILL NOT SUPPORT LIFE.	NO DATA. WOULD VARY WIDELY WITH COMPOSITION.		5.3 19.3	NEAR TOP OF STRUCTURE.	FROM DIGESTION OF SLUDGE.

\* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

CHART NO. 1

Gas	Chemical Formula	B.T.U. Calorific Valve	Specific Gravity or Vapour Density	Explosive Limits in air % by volume		Theoretical air required for complete combustion	Minimum Ignition Temperature ° Fahrenheit	Maximum Flame Temperature ° Fahrenheit	Flame Speed Per Sec.	Auto Ignition Temperature
				Lower	Upper					
Methane	CH <sub>4</sub>	913.1	0.55	5	15	9.56 to 1	1170°	3484°	0.85	1000
Natural gas		1027	0.6	4.9	15	10.00 to 1	1170°	3562°	0.99	1000
Propane	C <sub>3</sub> H <sub>8</sub>	2385	1.52	2.10	10.10	23.9 to 1	898°	3573°	0.95	871

Taken from Factory Mutual's Handbook of Industrial Loss Prevention.

Chapter 37

Chart No. 2

1967

The underground pumping station was destroyed by an explosion of accumulated gases from solvents in the sewage.

The gas was ignited when the electric pump motor started on its automatic pump cycle.



NORMAL OPERATION OF THE CONVENTIONAL ACTIVATED SLUDGE  
SEWAGE TREATMENT PROCESS

Written by: A. R. Townshend, P. Eng.

Lecture given by: Mr. G. A. Missingham, District Engineer  
Division of Sanitary Engineering.

THE ACTIVATED SLUDGE SEWAGE TREATMENT PLANT

The activated sludge process is used in competition with the trickling filter process to provide secondary treatment. The main treatment units of the activated sludge process are the aeration tanks and the final settling tanks. Re-aeration is practiced at some plants. This is done in separate re-aeration tanks after the sludge is removed from the final settling tanks, and before it is added to the sewage, or by adding the sewage at a point along the length of the aeration tanks.

In modern plants pretreatment and primary treatment are usually provided ahead of the aeration tanks.

Chlorination of the final settling tank effluent may be required by the governmental control agency which in Ontario is the Ontario Water Resources Commission.

In complete treatment plants sludge and scum removed from these processes are given further treatment in digesters and/or sludge filters, sludge drying beds, sludge lagoons, and incinerators before being removed from the plant site for final disposal.

SCOPE

This lecture deals with control of the activated sludge process under normal operating conditions. Operating difficulties of the activated sludge process will be discussed in detail at future Sewage Works courses.



The operation of screens, cutting and grinding devices, grit removal units, pre-aeration tanks, primary settling tanks, and sludge treatment units are discussed by other lecturers in this Elementary Sewage Works Course.

### OPERATING CONTROL FACILITIES

The operating controls of the conventional activated sludge plant are at best comparatively limited. The operator should use to advantage what controls are provided at his particular plant.

The following control features are desirable:

1. Duplicate units which permit variation of the retention times to suit flow conditions;
2. Multiple blowers or variable speed blowers and time clock controls or adjustable weirs at mechanical plants which allow adjustment of the air supply;
3. Multiple pumps, variable speed pumps and adjustable air lifts to permit different return sludge rates;
4. Sewage, air, return sludge, waste sludge, and raw sludge flow-measuring devices which are necessary for close control of the treatment processes;
5. Laboratory equipment for conducting those control tests which are essential for efficient operation.

Unfortunately, in many cases, it is necessary to omit some of these control features in the original design in order to keep the initial, capital cost of the sewage plant project within the financial means of the owner. Laboratory equipment is one important item of plant control which can be provided by the owner at low annual cost after the plant is completed.

## THE ROLE OF THE OPERATOR

The success of any sewage plant in meeting the pollution abatement requirements for which it is intended depends on intelligent application of skill and knowledge by the operator. This knowledge should include understanding of essential plant design factors and the fundamental principles upon which the various plant units are based.

At activated sludge plants the operator is better equipped to cope with emergency situations and to overcome problems which may be peculiar to his particular plant if he has a thorough understanding of the principles of the activated sludge process.

## STARTING A NEW PLANT

Before starting a new plant, it is important that all tanks and piping are free of debris; that all mechanical equipment is in good working order and properly lubricated. It is good practice to check these items by first filling the tanks with water.

The next step is to pump the water out and to start the sewage flowing through the plant. It is desirable to start treatment with about one-fourth to one-third of the incoming flow, using only those portions of the plant needed to handle this flow. When the units required are filled, aeration should be commenced and set to run continuously. The sewage from the primary settling tanks should be by-passed around the secondary units for twenty-four hours. The primary effluent fed to the aeration tanks should then be increased slowly. All the settled activated sludge should be returned with none wasted. Suspended solids tests should be performed daily. When the mixed liquor suspended solids concentration reaches 400 or 1,000 ppm for mechanical\* and diffused air plants respectively, the total design flow may be turned into the aeration tanks.

Normally, a good activated sludge will be produced within one to four weeks.

\* - see note at conclusion of paper.

## REQUIREMENTS FOR OPTIMUM EFFICIENCY

A summary of requirements for optimum efficiency is given in Table 1.

Primary settling tanks are expected to remove up to 35% of the 5-day BOD and 65% of the suspended solids in the raw sewage. A sewage treatment plant utilizing the conventional activated sludge process is expected to remove between 90 and 95% of the 5-day BOD and suspended solids in the raw sewage and to perform with reasonable stability under proper operation.

## AERATION TANK OPERATION

In the operation of aeration tanks, the operator has three controls of activated sludge quality: aeration period; the volume of air supplied; and the mixed liquor suspended solids concentration.

### Aeration Period

In some plants where only one aeration tank is provided, the aeration period is fixed.

Where more than one aeration tank is provided, the aeration period can be adjusted by cutting units in and out of service.

### Air Supply

The actual demand of activated sludge for oxygen does not give the plant operator a useful way of determining the amount of air required. He must depend on the amount of oxygen remaining dissolved in the liquid to guide him in the regulation of the air supply.

The dissolved oxygen in the mixed liquor at the end of the aerator should not be less than 1.0 ppm by the Modified Winkler method. This is considered to be the minimum amount necessary. The optimum dissolved oxygen concentration at the end of the aerator is between 2.5 and 5.0 ppm.

It is most difficult with the high oxygen requirement at the beginning of an aerator to make a dissolved oxygen test at this point. It is practical to run the test on the liquid at the end of the tank where the demand rate is much less. It is hoped that if there is an appreciable amount of oxygen left at the end of the aeration period, the initial requirements are satisfied.

The dissolved oxygen content to be carried at the end of the aeration tanks to give best results is expected to vary from plant to plant.

Steps that may be taken to obtain this control are indicated below:

To Increase Dissolved Oxygen

1. Increase air supply by -
  - (a) Increasing blower speed or use of mechanical device;
  - (b) Starting an additional blower.
2. Decrease sewage rate of flow by -
  - (a) Placing more aeration tanks in operation;
  - (b) By-passing part of aeration tank influent to the receiving stream. (This procedure should be used only as a last resort.)

To Decrease Dissolved Oxygen

1. Decrease air supply by -
  - (a) Decreasing blower speed and use of mechanical device;
  - (b) Shutting off a blower;
  - (c) Wasting air to the atmosphere.

2. Increase sewage rate of flow by -

- (a) Taking aeration tanks out of operation;
- (b) By-passing part or all of the raw sewage directly to the aeration tanks.

Increasing the return sludge rate raises the dissolved oxygen in the return sludge, but decreases the aeration period. This control factor must be used with discretion.

The air blown through diffusers must be clean if the diffusers are to remain unclogged for substantial periods of time. The efficiency of air application is proportional to the pressure required to drive the air through the diffuser system. The pressure loss in the diffusers increases as dust is deposited on the underside of and in the porous medium.

The air filter system should be maintained free of dust accumulations at all times. Diffuser cleaning is a difficult operation at best and is costly in time and labour. Cleaning methods such as treating with acid, caustic soda, spalling, and sand blasting can be used effectively.

#### Mixed Liquor Suspended Solids Concentration

Variation of the mixed liquor suspended solids concentration is the most flexible method of controlling activated sludge quality. By increasing or decreasing the amount of sludge carried, the 5-Day B.O.D. loading to solids ratio can be kept nearly constant. The process should be maintained at the ratio which gives the best adsorption-oxidation balance.

The optimum quantity of activated sludge carried will vary from plant to plant, but should be as high as possible without impairing its clarification and settling qualities and without depleting the dissolved oxygen in the aeration tanks.

To control the mixed liquor loading necessitates the measuring of the suspended solids in the aeration tank. The settleability of the mixed liquor is measured by the

30-minute settling test. The total dry weight of the suspended solids is determined by filtering, heating, and weighing in a properly equipped laboratory or from a centrifuge test calibration curve.

These two quantities are combined in the Mohlman sludge volume index to indicate the condition of the activated sludge.

$$\text{Sludge volume index} = \frac{\% \text{ settleable solids}}{\text{ppm suspended solids}} \times 10,000$$

The sludge volume index expressed as per cent solids is the Donaldson sludge density index.

$$\text{Donaldson sludge density index} = \frac{100}{\text{Mohlman S.V.I.}}$$

The maximum permissible concentration of aerator solids by the 30-minute settling test is related to the sewage flow and return sludge rate according to the following expression:

$$\begin{array}{l} \text{\% settled volume of} \\ \text{mixed liquor} \end{array} = \frac{\text{Return Sludge Flow}}{\text{Sewage Flow} + \text{Return Sludge Flow}} \times 100$$

For a return sludge rate of 25%, the maximum permissible cylinder volume is 20%. Where a return sludge rate of 35% is possible, the 30-minute settling test should not exceed 26% by this formula.

In the above generalization it is assumed that the plant is well loaded. For special cases where the amount of air is limited, the loading is low or the aeration period is long, it is desirable to operate the aeration tanks with a lower concentration of suspended solids in the mixed liquor.

With the return sludge rate fixed at 25% and the 30-minute settling test fixed at 20%, the sludge volume index will vary with the aerator effluent suspended solids concentration. For every aerator effluent concentration there is a critical sludge volume index above which the formation of settled sludge in the final tanks will exceed the return sludge rate.

If the sludge volume index increases and an attempt is made to restore final tank balance by reducing aerator effluent concentrations (by wasting), the sludge age is correspondingly lowered and the process will fail. On the other hand, if the sewage load should rise, it is necessary to further increase the aerator solids to maintain adequate sludge age. This imposes a correspondingly higher burden on the final settling tanks. The activated sludge process is, therefore, limited by the maximum return sludge rate possible.

This relationship among mixed liquor solids, return sludge rate, and return sludge solids is given by the formula:

$$(a + b) X = b y \text{ where}$$

a = sewage flow in MGD;

b = return sludge in MGD;

x = mixed liquor suspended solids in ppm;

y = return sludge suspended solids in ppm;

This formula was combined with the sludge index by D. E. Bloodgood to create the accompanying nomograph for use in activated sludge plant operation. The nomograph can be used to find the maximum concentration of suspended solids that should be carried in the mixed liquor for a given desired sludge index and return sludge rate. It is evident from the nomograph that as the sludge index increases the maximum allowable suspended solids concentration in the mixed liquor decreases. It can also be used to give the required return sludge rate to maintain uniform conditions when the sludge index and suspended solids concentration in the mixed liquor are known.

Other formulas have been developed to express the inter-relationship of the variables.



The expression developed by Lamb is:

$$\% \text{ return sludge} = \frac{S}{R-S} \times 100$$

where - S = % sludge aeration tanks (30-minute settling test)

R = % sludge return sludge (30-minute settling test)

This formula is useful where only the 30-minute settling test is conducted. For example, if the raw sewage flow was one million gallons per day and the 30-minute settling tests for the mixed liquor and return sludge were 20 and 95 per cent respectively, the return sludge rate should be 27%.

The formula given by Torpey relates the settled sewage suspended solids concentration to the suspended solids concentrations of the mixed liquor and return sludge.

$$\% \text{ return sludge} = \frac{C_a - C_p}{C_r - C_a} \times 100$$

where  $C_a$  = aerator effluent suspended solids in ppm

$C_p$  = primary effluent suspended solids in ppm

$C_r$  = return sludge suspended solids in ppm

For example, if the respective concentrations of suspended solids are 2,500, 90 and 10,000, the return sludge rate should be 32%. If the aerator suspended solids is 2,000 ppm, the return rate should be 26%.

In order to provide some flexibility it is better not to carry the aeration liquor suspended solids at the maximum possible level since in most cases purification can be carried out at substantially the same degree at lower concentrations.

However, as stated previously, there are good reasons for carrying the solids as high as possible. High solids decrease the tendency for sludge bulking, reduce frothing nuisance, and give protection against shock loads.



FINAL SETTLING TANK OPERATION

The performance of final settling tanks is related to the condition of the sludge and to the hydraulic characteristics of the basin.

Sludge is continuously removed from the final settling tanks in order to keep it as fresh as possible. If sludge is held too long it consumes the available oxygen and progresses into a septic or anaerobic state. In sludge with a high rate of activity this may result in gasification through denitrification and floating sludge at the surface.

As shown earlier under control of aerator solids, the proper rate of return sludge to prevent undue retention can be determined from the expression:

$$\frac{\text{Return Sludge Flow}}{\text{Sewage Flow} + \text{Return Sludge Flow}} \times 100 = \% \text{ settled volume of mixed liquor}$$

For example, if the 30-minute settling test is 20%, the quantity of return sludge should be 20% of the total flow of mixed liquor. This can be obtained easily where single tanks and meters are available.

The other rule is that the concentration of suspended solids in the return sludge must never be allowed to exceed the sludge volume index expressed as per cent solids. (The Donaldson sludge density index) Thus the maximum permissible concentration of return sludge would be 4,000 ppm for a sludge volume index of 250 and 10,000 ppm for an index of 100.

Whichever control method is used, the sludge depth should be checked by soundings at least once a week. The sludge blanket in the final settling tanks should not be allowed to exceed 2 feet in depth.

Density currents are induced in final settling tanks due to the fact that the specific gravity of the sludge mixture is greater than the clarified water in the tank. The activated sludge on entering the settling tank

falls almost vertically and then flows along the bottom of the tank, toward the outlet end. Currents near the bottom of the tank will establish secondary currents in the water layers above them in a reverse direction. This phenomenon will lead to a carry-over of sludge in the weirs from upwelling currents unless adequate weirs and baffles are provided.

Actual plant operation may indicate the need for weir relocation, increased weir length, and alteration of the inlet devices. Adequate baffling is also required to prevent surface short circuiting.

### SECONDARY SLUDGE WASTING

Waste activated sludge should be adjusted to keep the 30-minute settling test within the desired range. Where fluctuations make this control procedure difficult, the level of the sludge blanket in the final settling tanks should be used as a guide to sludge wasting. The level generally should not exceed one to two feet above the bottom of the tank.

At some plants, control is accomplished by wasting continuously. At other plants, it is necessary to adopt a wasting schedule so that small amounts are wasted slowly and uniformly during periods of low flow. Where the sludge is wasted to primary settling tanks this tends to improve the quality of the primary effluent.

Large volumes should not be wasted at one time. This reduces the 5-Day BOD to solids loading or sludge age and encourages rapid growth of the remaining activated sludge. If the primary settling tanks are not able to handle the loading, the sludge will be carried back into the aeration tanks and the wasting operation will be ineffective.

### FINAL SETTLING TANK EFFLUENT

If all goes well the final settling tank effluent should be clear and sparkling in appearance. Suspended floc particles should be absent.

It is the objective of the OWRC that treated effluents from activated sludge plants contain no more than 15 ppm of 5-Day BOD and suspended solids. This is possible with good operation where the raw sewage strength does not exceed 250 ppm 5-Day BOD and suspended solids.

NORMAL OPERATION  
OF THE CONVENTIONAL ACTIVATED SLUDGE  
SEWAGE TREATMENT PROCESS

Summary of Requirements for Optimum Efficiency

<u>Item</u>	<u>Requirements</u>
Micro-organisms	<p>A varied culture of different types of bacteria <b>with</b> Zoozlea ramigara and/or other gel formers <b>present</b>;</p> <p>Stalked, ciliate protozoa and free-swimming ciliates <b>present</b> without the smaller flagellate protozoa;</p> <p>Absence of the fungus, Sphaerotilus natans.</p>
Feed Characteristics	<p>The raw sewage be predominantly composed of a mixture of soluble, colloidal and suspended materials; soluble BOD being more difficult to process especially at lower temperatures;</p> <p>For average domestic sewage the feed contain between 8 to 18 ppm free ammonia as N and between 1.7 and 2.8 ppm phosphorus as P;</p> <p>The raw sewage be free of toxic materials.</p>
Temperature	<p>Optimum temperature of 82°F.</p>
pH	<p>Between 7.0 and 7.5</p>
Air Requirements	<p>(a) 0.5 to 1.5 cu. feet of free air per gallon of sewage;</p>

**Air Requirements (Cont'd)**

- (b) 500 to 700 cu. feet per lb. BOD removed when BOD loading 25 to 30 lb. per 100 lb. aerator solids;
- (c) 700 to 1,750 cu. feet per lb. BOD removed when BOD loading 25 to 12 lb. per 100 lb. aerator suspended solids.

**Aeration Period**

- (a) Diffused air - 5 to 7 hours;
- (b) Mechanical\*- 8 to 10 hours.

**Sludge Age**

3 to 4 days

**BOD Loading**

- (a) 25 to 30 lb. of BOD per 1,000 cu. feet of aeration tank;
- (b) 30 to 40 lb. of BOD per 100 lb. of aerator suspended solids for large plants;
- (c) 20 to 30 lb. of BOD per 100 lb. of aerator suspended solids for small plants.

**Sludge Quantity**

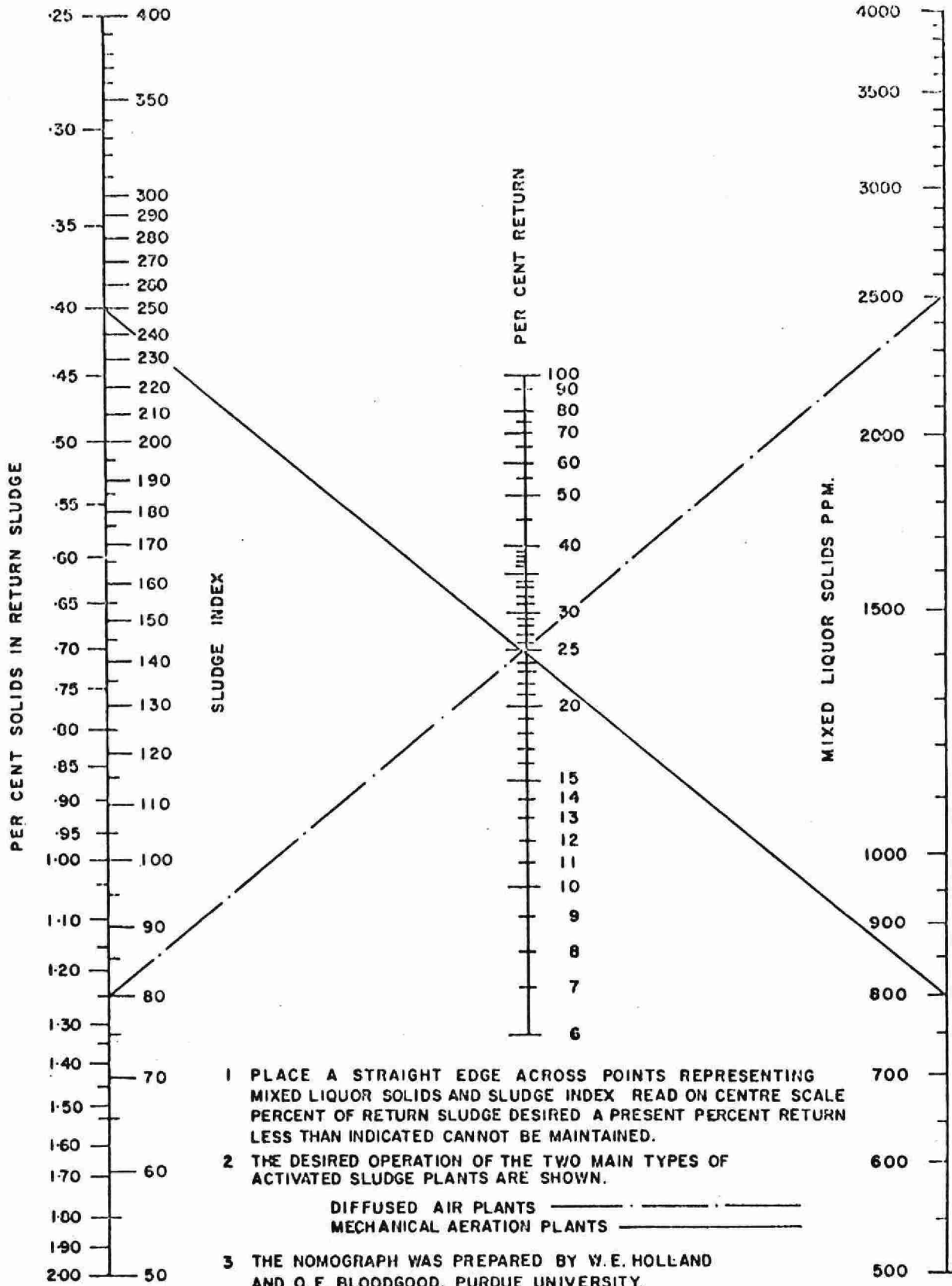
- (a) 1,500 to 3,000 ppm aerator suspended solids for diffused air plants;
- (b) 500 to 1,200 ppm for mechanical\*aeration plants.

# Sludge Quality

Volatile matter	-	60 to 85 % of total aerator solids
Alkalinity	-	100 to 200 ppm
Dissolved Oxygen	-	
Content at outlet	-	2.0 to 5.0 ppm
30-minute settling test	-	15 to 25%
Sludge Volume Index	-	(a) near 100 for diffused air plants; (b) about 250 for mechanical aeration plants*.

\* NOTE: Modern mechanical aerators of the turbine and high intensity cone type are equivalent to diffused air systems. Earlier mechanical aerators of the splash plate type, for example, were less efficient requiring longer aeration periods and lower mixed liquor suspended solids concentrations. In this paper "mechanical aeration plants" refer to those with the less efficient types of aerators.

# NOMOGRAPH FOR USE IN ACTIVATED SLUDGE PLANT OPERATION



BASIC CONSIDERATIONS OF THE CONVENTIONAL  
ACTIVATED SLUDGE TREATMENT PROCESS

G. H. Kay

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After primary treatment, usually by sedimentation, settled sewage still contains organic solids which are putrescible and can result in odourous gases and unsightly conditions, together with associated pressures on the receiving stream. These solids may be in a suspended, colloidal or dissolved state and may constitute forty to fifty percent of the original suspended solids and sixty-five to seventy-five percent of the original BOD, depending on sewage qualities and the efficiency of the primary sedimentation unit. As our municipalities grow, this becomes an excessive amount for the receiving streams to assimilate and efficient means of secondary type treatment had to be found.

In their initial form, the organic solids do not lend themselves readily nor economically to normal physical or mechanical methods of removal.

BIOLOGICAL PROCESSES

In biological processes, bacteria and other microbial life were known to be capable by using the material concerned in their life processes, of breaking down some complex organic substances, first into simpler, less putrescible organic compounds of nitrogen phosphorous and sulphur and finally to the more stable nitrates, phosphates and sulphates together with some gases and water. It was also known that if these processes took place in the presence of oxygen, the process was inoffensive. Without this dissolved oxygen, the process was accompanied by objectionable gases and unsightly conditions. The processes under consideration were usually of the first type (aerobic).



Therefore, since the solids of sewage are also organics comprised of carbohydrates, proteins and fats, together with bacteria and other micro-organisms, it was considered that the settled sewage could be treated by trickling filters or by plain aeration for a long period of time in fill-and-draw (fill-and-empty) operations, to completely stabilize or oxidize it. This latter process commonly required five weeks compared to the much shorter periods required by the biological or trickling filters and prompted further aeration process experimentation at the turn of this century.

## HISTORY

In 1913 in Manchester England, while utilizing this fill-and-draw aeration method, Ardern and Lockett discovered that if a portion of the relatively stabilized deposit or sludge remaining in the bottom of the aeration unit was left there to mix with the next batch of sewage, the purifying process was accelerated, and the time required for purification was reduced. This acceleration increased with each further increment of retained sludge added to each new batch of sewage, up to a limiting value, when the sewage was stabilized or oxidized after 24 hours of aeration time. This was a real improvement over the five weeks usually required for plain aeration, and Ardern and Lockett properly assumed that the acceleration and the associated reduced aeration time required, was attributable to some faculty of the "activated" deposit or sludge.

## DEVELOPMENTS

It was but a short time before flow-through units were evolved wherein this "activated" deposit or sludge was settled in a separate unit and returned rapidly to the aeration unit, while the sparkling effluent was safely discharged to a watercourse. The improved efficiency possible then allowed this process to commence to compete with the trickling filters which were then in general use.

Subsequent designers eagerly seized this improved method of secondary type sewage treatment but then as now, some aspects of the process were not completely understood, and for a long time basic considerations produced almost standard units having the following aspects:

Primary settling period - 1 hour

Aeration contact period - 4-8 hours

Suspended solids concentration - average 1500 ppm

Quantity of air required - 0.5 - 2.0 cu. ft. per  
gallon of sewage

Final settling period - 2 hours

Quantity of the return sludge - 10-30% of sewage  
flow

Lacking a full knowledge of the mechanics of the process, a designer could provide a plant using these design guides which could be made to operate reasonably well for average sewage strengths, providing that flows do not regularly exceed design flows. However, with the variation in sewage strengths and flows, and the demand for consistently high efficiencies, serious operating problems arise.

### INVESTIGATIONS

Extensive investigations performed during the last fifteen years have affirmed the true biochemical nature of the activated sludge process and have assisted in deriving new, more proper controls and modifications for efficient operations.

### BACTERIOLOGY

Generally, it has been shown that in an activated sludge process, the clarification of settled

sewage and the removal of the organic pollutants thereof, is effected by the life processes of bacteria which predominates the activated sludge. The many varieties of these, including the slime-producing bacteria, *Zooglea Ramigera*, are primarily responsible for the biological oxidation, to stable compounds, of the nutrients in the sewage with the subsequent physical change and clarification thereof. There are many varied organisms each with its own role to play. As the bacteria are able to utilize human wastes, so other organisms in the activated sludge mass are able to utilize the waste from the bacteria. If the sewage is heterogeneous, (containing many varied constituents), the activated sludge colony is also heterogeneous. If one nutrient predominates, one organism, specie or strain will grow to predominance.

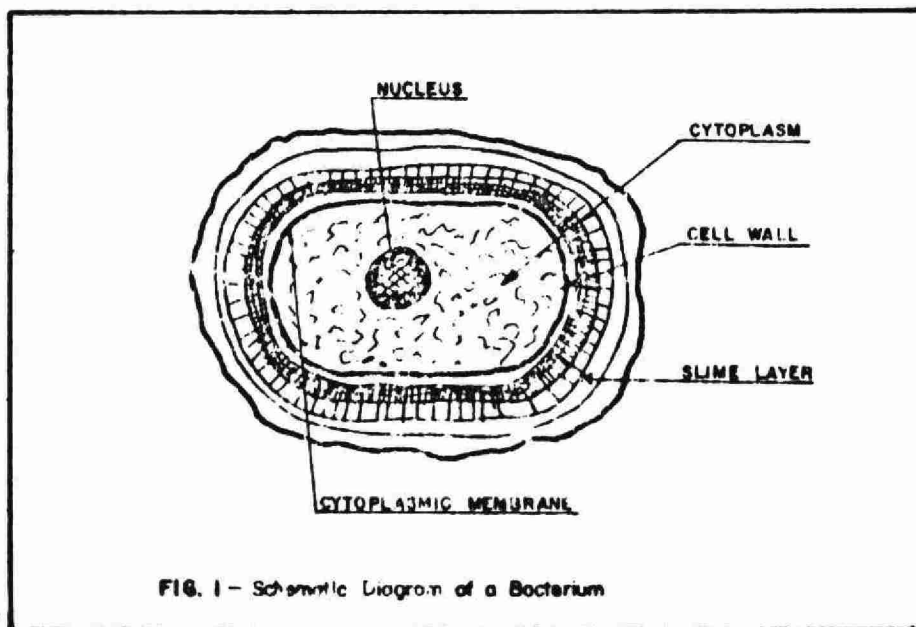


Figure #1 shows a bacterium surrounded by a slime layer. In the process of violent mixing at the head of the aeration tank, the finely divided and colloidal particles of the sewage are trapped or adsorbed onto this slime and the enlarged unit strikes and joins others to form feathery flocs. These also act as sieves and entrap more material to yield the active sludge mass in the aeration unit. The biological flocculation therefore acts similarly to the flocculation at water treatment plants via various forces, to remove for sedimentation, the microscopic particles in the water that are not easily otherwise removed.

As Mr. Vlassoff has said, the bacteria must have the nutrient pass through the cell wall to the inner cytoplasm (protoplasm) in order to be utilized, and if you remember his drawing, you can see that violent mixing is required, so that the nutrient particles may find a path into the cell. This mixing also continually breaks up these flocs so that each organism, be it on the surface or in the centre of the floc mass, may have a proper intimate oxygen supply for the support of its life process. This also drives off waste gases such as  $\text{CO}_2$  produced by the bacteria and which would be toxic to them. The dissolved nutrients are soon drawn into the cell by absorption processes but the suspended and colloidal portions that are trapped or adsorbed in the slime layer are first acted upon by extra-cellular enzymes exuded by the cell, before being absorbed therein. Intra-cellular enzymes further prepare the material for use by the bacteria in its life processes or metabolism (by oxidation) and production (by synthesis) of new protoplasm and cells.

### SLUDGE CONDITIONING

The process of absorption of dissolved material and the entrapping or adsorption of suspended and colloidal material for future utilization, is usually completed within one-half hour and the sewage will then clarify and, partly because of the entrapped and relatively heavy solids, the sludge will often settle properly. However, in

the closely following rapid growth phase, the increased quantities of protoplasm in the individual cells reduces their density and therefore deteriorates their settling properties. To produce a good effluent, it is necessary to adequately separate the sludge from the liquid to be discharged. There is little advantage in having a mixture that will clarify, if it requires such a long time to do so, that large expensive final settling tanks are required. Also, in its present form the sludge is not considered to be truly effective for future solids removal as, with its adequate stored food or energy, the cell itself is not capable of readily clarifying more sewage by adsorbing more solids, when returned to the head of the aeration tank. Therefore, for both of these reasons, prior to discharge to the settling tank, the mass of activated sludge is retained under optimum aerobic conditions (aerated) while the processes of biochemical oxidation proceed to improve its settling and clarifying properties by reducing this stored food and extra bacterium size. In the conventional activated sludge process, this aeration should continue until the sludge has spent a period in the "death" phase which will be discussed later.

#### BIOLOGICAL OXIDATION CURVE

In all biological oxidation processes wherein:

1. The environment is completely aerobic (adequate oxygen),
2. Conditions are optimum with regard to temperature, toxicity and pH at all times,
3. The environment (sewage) contains all of the essential nutrient elements required for biological growth,
4. A definite, initially abundant amount of food is available,

The number of bacteria will alter in a manner resembling the curve in Figure #2.

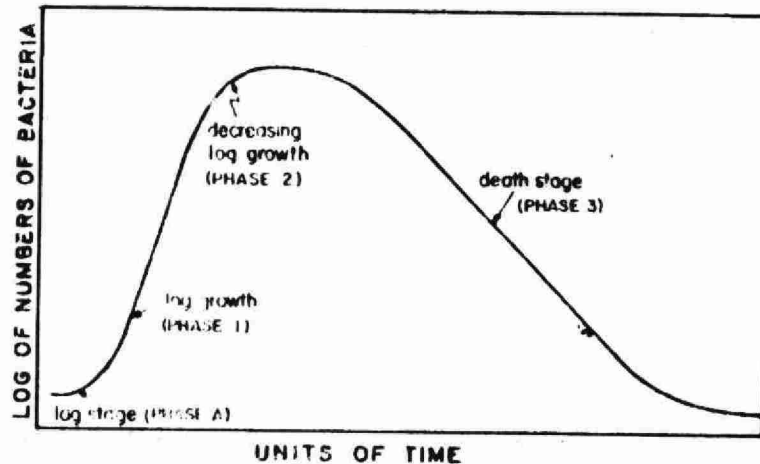


FIGURE 2 — Growth phases in biological oxidation processes

This is the general curve for all biological oxidation processes where these conditions exist, and indicates how the numbers of bacteria or sludge mass tend to increase and then decrease with the passage of time or, similarly, as the sludge mass progresses down a conventional aeration tank. This is the curve of the biological growth that occurred in Ardern and Lockett's initial fill-and-draw aeration experiments and would approximate the sludge mass growth in an underloaded flow-through aeration tank not employing activated sludge and having a sewage flow relatively constant in quality and quantity. Naturally, the specific curve applicable in any process would be a function of the

predominant micro-organisms, the sewage's chemical composition, temperature, etc., and in part that is why specific units of time and specific units of bacterial numbers are not shown on the graph.

However, using this general curve which is common to each, it has been observed that without the correct addition of "acclimatized" or "activated" sludge, an inactive phase or "lag stage" occurs when no appreciable growth in bacterial numbers or masses occurs with the passage of time, apparently while the micro-organisms "acclimatize" themselves to the food supply (organic solids) of the sewage.

#### LOG GROWTH (PHASE I)

I am indebted to Mr. Vlassoff for his excellent presentation on the "Bacteriology of Sewage Treatment" and I would refer you again to his paper.

He has indicated that the bacteria utilize some of the stored sewage nutrients in their regular life processes (metabolism) through oxidation, giving off as waste products, CO<sub>2</sub> and water. Some of the stored nutrient is also used in producing or synthesizing more cell material or protoplasm (similar to photosynthesis in plants). The bacterium enlarges in size and finally splits to form two duplicate bacteria which then progress to repeat this process. Under the optimum conditions previously mentioned, this increase in numbers takes place at a maximum rate of growth or log growth rate with the associated maximum rate of BOD reduction. It is limited only by the mean (average) generation time of the system. This is the time for a bacterium to grow to full size from the time of splitting (fission), or approximately 20 minutes. Some investigators feel that this time for a bacterium to develop and completely divide into two cells is extended by existing inadequate aeration processes. During this growth stage, approximately 57 percent of the BOD removed is synthesized or converted into new cell material. Forty-three percent is used or oxidized in the cell's basic life processes (metabolism).



### DECREASING LOG GROWTH (PHASE II)

At a certain point in this phase, the food as represented in this case by the nutrient value of the sewage, is inadequate to support this rapid increase of bacterial masses and results in a decreased rate of growth (decreasing log growth) proportional to the food remaining. Ultimately, at approximately the top of the curve, this supply becomes only adequate to maintain the natural life or metabolism of the existing bacteria and growth approximately ceases.

### DEATH PHASE (PHASE III)

As aeration continues, eventually this supply becomes further reduced and the bacteria commence to absorb the protoplasm of their own bodies by auto-oxidation as humans might utilize their fat layers, and if continued, will result in the death of the cell. This therefore is called the "death phase". This utilization or reduction of the protoplasm increases the density of the masses and so assists in later sedimentation. On the graph this phase of decreasing masses is represented by that portion to the right of the top of the curve. Extended aeration time, as in the misnamed total oxidation process, is required to effect almost complete reduction of the sludge masses as indicated by the right end of the graph.

### ACTIVATED SLUDGE CURVE

In an activated sludge process, the elimination of the lag phase by the addition of large numbers of acclimatized or "activated" bacteria to the head of the aeration tank, yields a curve as shown in Figure #3. Also, since the receiving stream is capable of assimilating some BOD represented now by the sludge mass, and since some of the sludge is wasted to the primary tanks for more economical disposal in anaerobic digesters, the sludge mass is not subjected to the aforementioned extended aeration.



Therefore, this phase, represented by the extreme right end of the graph (Figure #2) is usually not applicable to the sludge mass in the conventional process. Subsequently, the conventional activated sludge process generally confines the micro-organism colony to a phase straddling the top of this curve (Figure #3).

Now, if this drawing can be borne in mind, the causes for changes in the operations at any conventional activated sludge plant and at any plant using a modification thereof can be better understood.

The conventional plant is best operated to keep the microbial concentration actively growing at the head of the aeration tank to provide rapid clarification by adsorption and absorption of the solids with oxidation and synthesis of the stored material progressing as the sewage flows down the tank, including a period in the auto-oxidation or death phase to improve the settling and later adsorptive or clarification properties of the sludge.

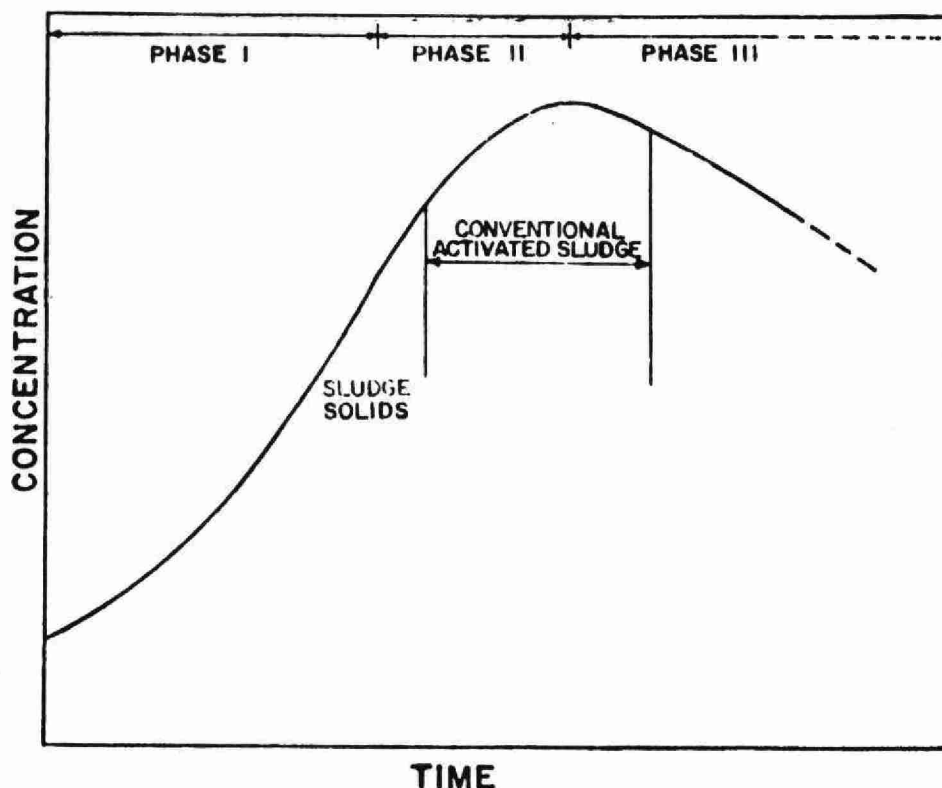


FIGURE 3 - Sludge growth for activated sludge.

### CURVE CHANGES

If a toxic material is added to the regular sewage the lag stage may re-appear. If a greater quantity of food becomes available, (pounds of BOD, primarily of the sewage organic solids) or if a period of hydraulic overload occurs, the sludge mass will not have been in the auto-oxidation phase long enough to produce a quick settling, highly absorptive sludge (i.e., the plant is overloaded).

If a comparatively lesser quantity of food becomes available (pounds of BOD) or if hydraulic underloading occurs, the sludge will have spent an excessive period in the auto-oxidation phase and although the sludge will be relatively heavy and settle rapidly, those cells that are almost completely oxidized or mineralized, tend to float out to spoil the effluent quality. The remaining returned activated sludge tends to be less active for subsequent sewage clarification.

Similarly, the curve characteristics will change with severe changes in aeration tank solids concentrations.

### F:M OR FOOD-TO-MICRO-ORGANISMS RATIO

In summary, following adsorption and clarification, the growth-synthesis portion of the process must be kept in balance with the auto-oxidation-death portion, to keep the sludge masses actively growing and subsequently self-consuming as they pass through the aeration unit in removing and utilizing the putrescible organic solids in the sewage.

Therefore, primarily, a given quantity of food in the form of organic sewage solids will properly support the life of a given quantity of active micro-organisms for the process.

And so the theory of food-to-micro-organisms or BOD to sludge solids relationship gains predominance.

For a given sewage strength and sewage flow (pounds of organic solids or more correctly pounds of BOD) there must be a proper micro-organism balance (pounds) based on these concepts.

To provide a vessel for this action, the designers have found that the concept of approximately 35 pounds of BOD per 1000 cu. ft. of capacity is a proper value to use in calculating aeration unit capacity. In the F:M or food-to-micro-organism relationships, Hazeltine has shown that a loading of 35 lbs. of BOD entering the aeration tank per 100 lbs. of sludge solids (representing active organisms) has proven to be efficient, while values of 0.20 to 0.40 have also been used.

This is basically the reciprocal of the Sludge Age of 3-4 days proposed by Gould and Edwards. Due to the varied composition of sewages, care must be taken not to compute aeration tank suspended solids as being totally active organisms. The use of organic (volatile) sludge solids values in computations as representing active organisms, is an improvement and perhaps a computation based on free nitrogen would be more correct.

Therefore, knowing the average strength and flow rate of the settled sewage, the optimum range of aeration tank suspended solids for best operating efficiencies is known and return sludge wasting rates must be adjusted to keep these solids within this range.

Due to the growth of the bacteria in utilizing sewage nutrients, there will be a tendency for excess sludge to build up in the final settling tank where it may tend to decompose. There will be approximately 0.5 lb. of growth of the sludge mass for each pound of BOD stabilized. This must be removed from the system and is accomplished by wasting sludge to the primary settling tank for subsequent disposal.

SLUDGE SETTLING CHARACTERISTICS

As previously stated, an efficient final sedimentation tank and a rapidly settling floc are necessary. In previous lectures you have discussed the 30-minute settling test, the sludge volume index (S.V.I.) or Mohlman Index, and perhaps the Donaldson Index or  $100/\text{S.V.I.}$ . The settling characteristics of the sludge as we have shown, primarily will be dependent upon the stored energy or food level thereof and therefore, generally depends upon the phase of the biological oxidation curve that applies to the sludge as it enters the sedimentation unit. In other words, after 30 minutes settling the sludge may appear compact or fluffy depending upon the relative quality of stored energy or protoplasm. The quantity that settles in 30 minutes will be a function also of the concentration of sludge solids in the system. Therefore, at a given sludge return pumping rate the weight of solids or active micro-organisms therein, will be a function of these two factors which are included in the sludge volume index or Mohlman Index and the Donaldson Index =  $100 / \text{S.V.I.}$ , and in part this value indicates the life phase on the biological oxidation curve of the sludge entering the final sedimentation tank. A proper value here generally suggests that the sludge has entered the death phase and will ordinarily have settling characteristics conducive to producing superior effluents.

Due to the inter-relation of these factors, it has been found that the concentration of suspended solids in the return sludge should never be allowed to exceed this sludge density index (Donaldson Index) expressed as percent solids. For example, the maximum permissible suspended solids concentration of the return sludge would be approximately 10,000 ppm for a Mohlman Index of 100.

Together with the defined F:M ratio and the known optimum sludge index ranges these new guides suggest that the maximum return sludge rate possible at any plant due to unit capacities there is important. Mr. Townshend will be presenting pertinent formulae and providing a nomogram that will offer a visual assessment of these inter-relations.

### BASIC COMMENTS

For a certain sewage strength, (pounds of BOD) the organisms remove the putrescible solids and settle most rapidly for subsequent removal, within certain aeration tank solids concentrations. The rate of sludge wasting must be adjusted to maintain these concentrations.

The rate of sludge return is adjusted to prevent a build-up in the final settling tank of the increased cell solids produced from the nutrients of the sewage by the organisms in their natural life processes.

We can now see that the air in the process is added to provide the living organisms with adequate oxygen to perform their normal life processes and must not be allowed to fall to a value that will restrict the process's efficiency.

### MODIFICATIONS

There are several modifications of the process to make it more efficient or economical, but each of these is really only adjustments in the life cycle of the micro-organisms in the activated sludge colony, to take advantage of certain definite physical and biochemical properties thereof. A common modification is the so-called total oxidation process, where an extended aeration period prolongs the period that the bacteria are in the death phase where they are experiencing auto-oxidation, in an attempt to minimize the amount of sludge that will require ultimate disposal.

### SUMMARY

It has been said that "The micro-organisms and the tiny macro-organisms are the real operators of sewage treatment processes; the function of the human operators is to furnish optimum environmental conditions required by the biological life". If we will bear this general thought in mind we may be more able to deal efficiently with the ever-increasing quantities of sewage requiring adequate secondary treatment before ultimate disposal to our watercourses.

PROBLEMS CAUSED BY INDUSTRIAL WASTES  
IN SEWERS AND SEWAGE PLANTS

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As operators at sewage treatment plants, I am sure you have all experienced the problems that can be caused by industrial wastes. In fact, you have probably thought that life would be very simple if it were not for the occasional slugs of grease say, that send you scurrying for skimming buckets and cause you to work overtime. You may damn this problem when it occurs, but let us examine the situation more thoroughly. Any one of you can operate a plant under ideal conditions but how many of you have the foresight and ingenuity to circumvent problems, such as those resulting from industrial wastes, and still keep the plant from becoming upset? You who can, regardless of whom you are working for, are reliable and valuable employees.

It is customary for a municipality to enact a sewer-use by-law in an attempt to control the characteristics of the waste flows being discharged to the sanitary system. If industries comply with this by-law, there should be no problems either in the sewers or at the plant. The salient features of such a by-law are that discharges must have the following characteristics:

1. temperature - not greater than 150°F.
2. pH - between 5.5 and 9.5
3. organic loading as measured by the biochemical oxygen demand (BOD) - not greater than 300 parts per million (ppm).
4. suspended solids - not greater than 350 ppm.
5. toxic materials should not exceed the following levels:

cyanide as HCN	-	2 - 5 ppm
phenols	-	0.1 - 1.0 ppm
sulphides as H <sub>2</sub> S	-	2 - 5 ppm
metals	-	3 - 10 ppm



6. oils and greases or those substances soluble in ether -
  - (a) of mineral origin - not greater than 15 ppm
  - (b) of animal or vegetable origin - not greater than 100 ppm.
7. there must be negligible quantities of explosive, inflammable and/or radioactive materials present.
8. flow volumes must be such that hydraulic overloading of the system will not result.

It may be noted at this time that the effect of any one industrial discharge on the entire sewage flow will be proportional to their relative volumes. As most industrial wastes are amenable to treatment with domestic sewage in municipal treatment plants, it may be possible for a municipality to accept and treat wastes that do not comply with the by-law limits and still not upset the operation of the sewage treatment plant. The municipality may wish to supply this additional service at no extra charge or they may require a special agreement with the industry and additional money for this service. Normally there is a section in the by-law that makes provision for this arrangement. In order that the municipality may decide how to handle any particular situation, they must know the probable effect of any waste flow on their sewers and sewage treatment plant.

An industry views the treatment and disposal of its wastes as a matter of strict economics. It expects and deserves treatment of flows within the by-law limits for the normal sewer rate charge. If the municipality will accept a higher strength waste for a sum less than that needed to pretreat the wastes to by-law limits, it is good business for the industry to use this method of disposal. Many times the full strength waste cannot be treated at the municipal plant and it is then up to the industry to pretreat to a level which is acceptable to the municipality and economical to the industry. It is quite often easier to remove contaminants from a waste flow at the source within the industry, and this should be done where possible. It must be emphasized however, that the responsibility for ensuring that wastes from an industry are treated to the required level remains solely with the industry.

The problems that may be anticipated in sewers from flows not in compliance with sewer-use by-laws may be outlined under the following headings:

1. Flows - Excessive or fluctuating flows may overload the hydraulic capacity of a sewer and cause backing up of sewage into basements, or overflowing at pumping stations.
2. Temperature - The higher the temperature of a waste discharge the greater the biological activity in the sewer (rate doubles for every 10°C. rise). Thus the oxygen supply is quickly depleted and septic conditions occur. Also, high temperatures accelerate corrosion and place thermal stresses on the sewer pipes and joints.
3. Suspended Solids - May settle in the sewers and cause blockage.
4. pH - Variance beyond the acceptable limits will result in corrosion of the sewer.
5. Oils and greases will build up on the inside of the lines and reduce the sewer capacity.
6. Dissolved Salts - Certain dissolved salts may precipitate out in the sewers and lead to blockages and/or corroding conditions, e.g.,  $\text{Fe SO}_4 + \text{Ca(OH)}_2 = \text{CaSO}_4 + \text{Fe(OH)}_3$

More important from the sewage treatment plant operator's point of view, however, is the effect of industrial waste discharges on the operation of the sewage treatment plant. The operator must consider himself somewhat of a doctor in that he must first of all note the symptoms, then diagnose the type and extent of the illness and assess the effect it will have, or has had, on the various processes. Finally, and most important, he must take quick remedial action to offset the changing conditions. The various characteristics of industrial waste discharges that are of concern to a sewage plant operator will be covered under the headings:



- (a) detection
- (b) effect on:
  - 1. primary section
  - 2. biological processes
- (c) corrective action that may be taken.

1. Flow - excessive or surging flow conditions may be noted on the flow measuring devices within the plant or simply by the level of the flow on the walls of the channels. High flow rates will tend to flush the various tanks out and thus affect the detention times and the treatment provided. Little can be done to alleviate this condition at the sewage plant, as it should be corrected at the industry where the flows may be equalized.

2. Temperature - the rate of biological activity increases with temperature in a waste flow and the resulting septic conditions may be noted by the smell and low dissolved oxygen content of the raw sewage at the plant. A septic sewage will cause septicity in the primary clarifiers and exert an increased oxygen demand in the secondary biological section. The action required in this case would be to pre-aerate or pre-chlorinate the raw sewage flow.

3. pH - a waste with a pH outside the accepted range (5.5 to 9.5), in addition to creating corrosive problems throughout the plant, will tend to impair the settling and biological processes. This condition may be noted by checking the waste flow with pH paper at regular intervals and again little can be done at the plant as the situation should be corrected by having industry neutralize its wastes prior to discharge.

4. Organic loading (biochemical oxygen demand - BOD) - high strength industrial discharges will show up in the 5-day BOD test but this is of no assistance to the operator who is concerned with the conditions at any given moment. These high strength wastes are usually characterized by an unusual colour (e.g., red; indicating blood, dye, etc.), smell (e.g., a septic smell because of the rapid depletion of oxygen in the sewer lines) or the inclusion of tell-tale solids (feathers, hair, etc.). If the high strength is due mainly to dissolved components, it will have little effect on the primary section, but will create a high oxygen demand

and extreme sludge growth in the secondary biological section. If due to suspended matter, additional quantities of sludge will accumulate in the primary tanks and the digesters may be taxed beyond capacity. The action that should be taken at the plant would include carrying a higher concentration of solids and air in the aeration section and the possible addition of alkaline materials to the digesters as well as additional hauling of digested sludge so that a correct environment may be maintained for the anaerobic decomposition process.

5. Suspended solids - this characteristic of the waste flow is one of the most recognizable and usually a close examination with the naked eye will reveal unusual conditions which should be taken into account. The majority of the particles in suspension should settle out in the primary settling tanks and while most will be amenable to anaerobic treatment some such as clay, chicken beaks, hair and bark will decompose very slowly and thus use additional digester capacity. Adjustment in digester operation as well as cleaning of the digesters may be required if these solids are allowed to get through the preliminary screening devices.

6. Toxic materials - toxic materials such as copper, chromium, phenols, etc. may be difficult to detect in the raw sewage if they are in low concentrations. Should either the aerobic or anaerobic biological section be upset, however, toxic materials should be one of the first suspects. A laboratory analysis is required to confirm any suspicion in this regard. Higher solids could be carried in the aeration section to help in preventing an upset.

7. Oils and greases - these ether soluble materials will usually come to the surface in the grit tanks and primary clarifiers and their presence is thus readily apparent. If they can be skimmed, either by means of the regular skimming facilities, or manually, they should have little effect on the operation of the plant other than to deface the areas to which they cling.

It may be noted that in most cases, sophisticated laboratory equipment is not a necessary part of good sewage plant operation. More important is the ability of the

operator to adapt his thinking to the situation at hand and to take proper remedial action.

A resourceful operator should not only operate the plant as well as possible, but should also note the time and conditions of any upsets at the plant. He should then attempt to determine the section of the system from which the upsetting discharge came and to define as closely as possible the problem industry. Armed with this information the municipal officials, after investigating conditions at the industries in the area, should be able to locate the culprit and thus be in a position to enforce their sewer-use by-law.

#### SUMMARY

If, as a sewage treatment plant operator, you can operate a plant well under adverse conditions such as extreme industrial waste loading, you have reason to feel proud. The more high strength wastes that can be treated in your plant without process upset, the better service your employer is providing. Just remember, if you recognize the type of waste you are getting and how it may affect the plant, then you will have a chance to adapt the operation to treat it with a minimum of problems.

## DIGESTION OF SLUDGE

G. R. Trewin

Assistant Director  
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### PURPOSE

A primary purpose of sludge digestion is to reduce the complex organic matter present in the raw sludge removed by sedimentation processes to a simpler non-objectionable state. Digestion produces a sludge more amenable to dewatering, without nuisance, and renders the sludge fit for easy disposal by lagooning, dewatering on sand beds, and direct application to farm lands, golf courses, parks, etc. Digesters also reduce the volume of sludge and in doing so produce gas which can be utilized for heating purposes or gas engine operation.

### PROCESS

The digestion process covered in this lecture is that effected in the anaerobic range. Digestion or biological degradation can also be carried in an aerobic state.

The sludge consists essentially of two portions, a solids portion composed of material settled in the clarifiers and a liquid portion containing materials in actual solution. The concentration of material in true solution is relatively low in raw sludge charged to the digester, essentially no higher than contained in sewage entering the treatment plant. These dissolved materials are the only ones capable of affecting the micro organisms.

After sludge is sent to the digestion tanks, the organic materials, contained mostly in the solid portion of the sludge, are slowly hydrolyzed and brought into solution by the bacteria and enzymes present in the digester. Under normal conditions of operation, the organic matter is then quickly broken down into volatile organic acids by a group of bacteria commonly called "acid formers". The organic

acids are in turn decomposed into carbon dioxide and methane by a second group of bacteria commonly called the "methane formers". Because of this decomposition, the quantity of organic matter actually in solution normally remains low. There is, however, a buildup of certain salts in solution such as ammonium, calcium, and magnesium bicarbonates resulting from the breakdown of proteins and soaps. In a digester, these salts produce the natural buffers, which normally remain fairly constant at about 1000 to 3000 mg/l as calcium carbonate, dependent on the sludge concentration.

When unbalanced digestion conditions exist, the methane-producing organisms cannot remove the volatile acids as quickly as they are formed and consequently a buildup of the volatile acids results in solution. This buildup can take place very rapidly, and in a day or two the total concentration of the materials in solution can be more than doubled. To prevent a disastrous drop in pH from a large acid increase, alkaline material such as lime or sodium hydroxide, may be added for neutralization, the loading rate may be reduced, and dilution water may be added. Above all, the reason for the breakdown must be ascertained and eliminated.

Process failure can be caused by overloading, drastic load changes, temperature changes, and the buildup of toxic concentration of metal ions from industrial waste. The reduction of effective digester volume caused by bottom grit deposits and a scum blanket can also cause a process breakdown.

An average digestion facility being loaded by a domestic waste will reduce the volatile proportion in the sludge approximately 50 percent. This changes the volatile portion from 66 percent to 50 percent of the solids.

## DESIGN CRITERIA

### General

The capacity requirements for sludge-digestion tanks are primarily dependent upon:

- (a) the quantity of sludge that will be treated;
- (b) the temperature at which it will be digested;

- (c) the volume requirements for concentration, formation of supernatant, and storage of digested sludge;
- (d) the extent to which the tank capacity is effectively utilized;
- (e) the degree of digestion desired.

With the above five important variables, it is seen that the design problems are many and varied. Past design criteria allowed loadings of two to three pounds of solids per cubic foot per month on digesters heated between 90 and 95°F. Present design criteria allow loading up to and above eight pounds per cubic foot per month. The second figure makes no allowance for dead spaces, scum blankets and bottom deposits, or for shock loadings. The eight pound figure corresponds to a ten day retention period for a five percent (total solids) sludge. It is noted that up to 90 percent of the total gas production can be obtained in the first six days where good mixing is afforded.

#### Quantity of Sludge

The quantity of raw sludge will depend upon the amount and character of solids in the sewage, the removal of solids by the sewage treatment processes, any change in amount of solids produced by the treatment processes, and the concentration of solids in the sludge to be added to the digestion tanks.

Normally, it is considered that the suspended solids in a domestic sewage averages 0.20 pounds per capita per day. Allowances can be made for industrial waste loadings and garbage grinders.

The removal of suspended solids in the sewage treatment plant varies with the type of sewage treatment and the efficiency of the process as follows:

	<u>Removal Percent</u>
Primary Settling	40 - 60
High-Rate Trickling Filter	75 - 85
Conventional Activated Sludge	85 - 90



The treatment process may increase the amount of solids by conversion of dissolved and colloidal material to settleable solids. Biological processes may reduce the amount of volatile solids by aerobic digestion in trickling filter and activated sludge units.

Since detention period is one of the important factors in the capacity requirements of digestion tanks, the concentration of the sludge solids to be digested requires consideration. This concentration may vary from dense primary sludge at eight to 12 percent solids to dilute excess activated sludge at about 0.5 percent solids. In general, excess activated sludge is concentrated either in separate thickening tanks or, by mixing with raw sewage, in the primary sedimentation tanks. When excess activated sludge is mixed with primary sludge it is difficult to obtain densities exceeding five percent solids. In a small activated sludge plant an average sludge concentration of four percent would be considered good.

#### Sample Calculations

Example (a) Find required pumping time

Activated sludge process

Consider no gain or loss due to biological activity

Flow 1.0 mgd (1,000,000g)

S.S. concentration in raw sewage 175 ppm

Pump rating 50 gpm

Concentration of sludge 4% (40,000 ppm)

$$\text{Sludge quantity} = \frac{1,000,000\text{g} \times 175 \text{ ppm} \times 90\%}{40,000 \text{ ppm} \times 100}$$

$$= 3930 \text{ gallons}$$

$$\frac{3930\text{g/day}}{50\text{g/minutes}}$$

$$\text{Time of pumping} = 78 \text{ minutes/day}$$

Example (b) Find required pumping time

Activated sludge process

Consider no gain or loss due to biological activity

Population equivalent 10,000 persons

Pump rating 50 gpm

Sludge concentration 4%

Sludge quantity =

$$\frac{10,000 \text{ persons} \times .2\#/\text{person/day} \times 90\% \times 1,000,000}{100 \times 10\#/\text{gl} \times 40,000 \text{ ppm}} = 4,500\text{g}$$

$$\text{Time of pumping} = \frac{4500\text{g/day}}{50\text{g/m}} = 90 \text{ minutes}$$

### Temperature

Digestion can be effected in the mesophilic or thermophilic range, 50 to 100°F and 110 to 140°F, respectively. In the colder Canadian Climate, the unheated digested temperature may drop to 45°F where bacterial activity is very low. This being the case, all installations should be equipped with heating devices. Heating may be effected with the outside circulation of sludge through a heat exchanger or by heating coils in the digester itself. The most common temperature maintained in heated digesters is 90 to 95°F.

### Ten-State Standards of Digester Sizing

	<u>Cu.ft./Capital</u>	
	<u>Heated</u>	<u>Unheated</u>
Imhoff tanks	--	3 - 4
Primary	2 - 3	4 - 6
Primary + high rate filter	4 - 5	8 -10
Activated Sludge	4 - 6	8 -12

Lower digester temperatures require greater volume allowances in the design.

### Sizing of Digesters

In using the imperial loading criteria put forth in the Ten State Standards or the figures of 2 to 3# of solids per cu. ft. per month allowances are made for storage, shock loading capacity, scum blankets, and supernatant separation. The high rate digestion figures must be used with the understanding that allowances must be made for these items.

The ideal digester design will provide complete mixing, by mechanical mixers or gas recirculation in the first stage active digester. When thorough mixing is provided scum blankets are minimized or eliminated, and dead pockets are eliminated. In a second stage unit, the supernatant separation and storage functions are carried out. Even the second stage digester should be equipped with mixing or scum blanket removal facilities. It is noted that only with adequate mixing will the first stage digester capacity be fully utilized.



If carried too far, high rate digestion will transfer the scum blanket problems to the second stage digester.

In smaller installations, the digestion, concentrating, and storage functions must be effected in one tank. This type of installation is difficult to operate and seldom can all the necessary functions be carried out as effectively as desired.

## OPERATION

### Sludge Pumping

Sludge withdrawn from the sedimentation tanks should be as dense as can be handled satisfactorily through the pumps and piping. Thin sludge occupies digester space needlessly, and its excess water will have to be heated. On heavily loaded digesters, small sludge additions at frequent intervals, assures a uniform digestion rate. On fixed cover units, the loading cycle may have to be timed to correspond to the withdrawn program.

Excepting large plants, where careful control can be maintained over the sludge pumping operation, the piston type pump is to be preferred for digester loading. The centrifugal pump accentuates overpumping. When the sludge becomes thin, the pumping rate greatly increases, whereas the piston unit output remains near constant.

### Temperature Control

The most favourable temperature for digestion of sludge from predominately domestic origin is 90 to 95°F. Depending on the digester capacity available, lower temperatures may be used, but some margin of safety should be maintained. Generally, only the first stage digester, in a two stage operation, is heated.

In using internal hot water coils for heating, the water feed temperature should be kept below 130°F. High temperatures will tend to encrust a sludge cake on the coils. Excess water makeup requirements will indicate coil leakage and a smaller than normal temperature drop in the circulation coil water may indicate the formation of an insulation sludge layer on the coils. The use of internal heat exchange coils for digester heating is to be discouraged on all except small installations.

External Heat Exchangers are desirable because of accessibility for maintenance. These units also provide some mixing and at times the raw sludge feed is directed to the recirculation line to be actively mixed with the circulating "seed" sludge. In a system equipped with good internal mixing this step is to some extent redundant.

### Circulation and Mixing

The objectives of mixing or recirculation are:

1. Uniform transfer of heat to entire mass.
2. Intimate mixing of raw sludge with seed sludge mass.
3. Prevention of dead areas and scum blankets.

Many systems have been devised for carrying out the above functions. The most satisfactory results are obtained with digester gas recirculation units or internal mechanical mixers. Nevertheless, when these facilities are not available some results are obtained by recirculation using external pumps. Directing the recirculation sludge on top of the scum blanket may assist in controlling its buildup.

In operating mechanical mixers, they can be timed to effect required results. In no case should the timing cycle be set considering power economy alone. In an under loaded digester the mixing units need only be operated to prevent the formation of a scum blanket. The draft tube level may be varied to obtain the best results.

In operating mixers in a single stage digester, the problem of providing adequate scum blanket control along with good solids concentration and also a good supernatant is presented. As there is no absolute answer to this problem, single stage units are to be discouraged. Needless to say, mixing must be discontinued when the supernatant is withdrawn.

### Process Control

pH ranges from 6.8 to 7.2 have proved effective in maintaining a good digestion process. Experience has indicated that digester process failure will be far advanced before the pH will indicate the same. The volatile acids test has proved more effective in avoiding a process breakdown. Volatile acid concentrations between 200 and 500 will indicate satisfactory operation. A change from 300 ppm to 500 ppm might indicate a developing problem but until figures 1000 ppm are reached the gas production will remain high.

Recent research indicated that neutralizing compounds can restrict the process, therefore, the actual cause of the rising volatile acids concentrations must be found and corrected. Sodium hydroxide or lime may be used to assist process recovery when the cause of failure has been ascertained.

When the volatile acid concentration is found to be increasing above the normal range, the reason for this rise, insufficient heat, poor mixing, excess space loss due to the bottom deposited grit and scum blanket, toxic, metal ions, or overloading, must be found. Also, as a first step, the loading is reduced or stopped, as required, until corrective measures can be taken. In a two stage operation, the load can be transferred to the second stage digester. In a single stage, one tank, system, raw sludge may have to be removed by tank truck haulage.

In a two stage digestion process transferring may be effected via a connecting equalizing line or by direct pumping or a combination of the two. Occasionally, transferring must be carried out from the bottom withdrawal line or it may become plugged with grit and sand.

#### Withdrawal of Supernatant

A good supernatant should have a BOD, suspended solids, and volatile acids concentration below 500 ppm. The supernatant is withdrawn to reduce the moisture content of the digested sludge. In two stage units, the separation is effected in the second or cold digester. In single stage units it is difficult if not impossible to meet the above listed quality limits. When the withdrawal system is equipped with multi-level control, the best level must be found and used.

The digester supernatant must be returned to the main treatment process. When the suspended solids carryover is excessive the said process may suffer. Often the supernatant wasting is effected during low flow periods.

#### Operation Problems

##### 1. Drop of Gas Production

Gas production may be reduced by:

- (a) Organic overload causing process failure.
- (b) Toxic metals such as copper, nickel, chromium, and zinc may have a toxic effect on the organisms.

- (c) Reduced organic loading.
- (d) Increasing scum blanket.

A gas production of 15 cubic feet per pound of organic solids destroyed can be expected when effective digestion is taking place. The gas will analyse at 65 to 70% methane and 25 to 30 carbon dioxide. During start up and at process failure, the methane percentage will be greatly reduced. The gas yield from an activated sludge plant can be approximately 1.0 cu. ft. per capita. In an average digestion process, approximately 33 percent of the total solids in the raw sludge are reduced by the process. In more volatile sludges, the percentage will, of course, be higher.

From the above, it is seen that the gas production figures are important in watching the process as a whole.

When the cause of the process failure is ascertained the necessary corrective steps must be taken. The scum blanket elimination would appear to be one of the difficult problems to correct. The installation of proper mixing facilities is the only complete answer to scum blanket control.

## 2. Foaming

With poor mixing facilities, a heavy scum blanket may form. With heavily loaded units, this blanket may commence to digest, causing a foaming action. This foam may plug gas lines and overflow pipes. A process failure may develop.

The solution is to reduce the load on the digester and thoroughly mix the digester contents to eliminate the scum blanket. At the same time dilution, pH control, etc. may be required to prevent process failure.

## CONCLUSION

A few of the pertinent criteria to be used in evaluating a given digestion system have been reviewed. Various operational problems and procedures have been outlined. Anyone interested in further expanding their knowledge on this subject would be advised to consult back issues of the "Water Pollution Control Federation Journal". The Federation Manual of Practice, number 8, also has a thorough outline of design criteria. Much is written on the digestion process so it would be impossible to include a complete reference appendix in this volume.

## SLUDGE HANDLING METHODS

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### INTRODUCTION

Concentrated sludge and clarifier skimmings collected from the various sewage treatment processes must be disposed of in such a manner so as not to cause health or odour problems. The operation of an otherwise excellent plant is often greatly hindered by economy deletions made in providing equipment for the sludge disposal section of the treatment plant. Nevertheless, when a given plant lacks some of the desired facilities, good operation may in part overcome the presented difficulties.

### CLASSIFICATION OF SEWAGE SLUDGE

The following is a definition of sewage sludge:  
"Sewage sludge is the accumulated settled solids removed from sewage by sedimentation. Descriptive of its source, it may be termed primary, secondary, excess activated, or chemical. From the state or extent of treatment received it may be called raw, digested, elutriated, dewatered or dried."

The first sentence of the definition indicates that the source of all sewage sludges is sedimentation. However, it must be remembered that there may also be surface skimmings which are obtained by flotation. In the second sentence it is stated that sludge may be called primary, secondary, excess activated, or chemical depending upon its origin or source. Primary sludge is from the first clarifier through which the raw sewage passes. This is one of the first stages of sewage treatment but it may be eliminated at some plants. Secondary sludge is from the sedimentation tank in the secondary or biological section of a plant such as the clarifier after a trickling filter where the coating sloughed off the stones is settled out of the effluent prior to its discharge to the receiving

stream. Excess activated sludge is that portion of the settled sludge being returned to the aeration section of an activated sludge plant which is being wasted and not being returned (the 25 per cent commonly wasted at a lot of plants). Chemical sludge is that which is obtained by chemical treatment of a waste such as in some industrial processes and is not known to most sewage plant operators.

The third sentence of the definition indicates that there are still further names that may be applied to sludge. These are dependent on the state or the extent of treatment that has been given to the sludge. They are as follows:

Raw - this means that the sludge has had no treatment. It is just as it comes from the sedimentation tank.

Digested - the settled raw sludge has been given further biological treatment under controlled conditions in digestion units.

Elutriated - this essentially means that the raw sludge has been "washed" to prepare it for further treatment.

Dewatered - some of the moisture has been removed from the sludge to reduce the volume to be disposed.

Dried - most of the water is removed leaving a relatively dry waste material.

Raw primary sludge being that which is settled out of the raw sewage entering the treatment plant in the primary clarifier, contains bits of garbage, fecal solids, sticks, and other debris. It has a foul odour, is disagreeable in appearance (usually a grey colour), and being highly unstable will readily go septic. The raw secondary sludge is brownish coloured, less odourous and already partially decomposed. Then there is digested sludge which is even further treated and more acceptable in appearance and odour (similar to swampy earth). The digestion process and its resulting sludge will be described in much more detail in other lectures.



Elutriated and dewatered sludges are essentially the same as the above three types of sludge but a portion of the water has been removed and the chemical nature may be changed slightly. Otherwise, the sludges are similar in appearance and odour.

An interesting point about sludges which may be deceiving by their appearance is their moisture content. Depending on the source of the sludge and the nature of the solids in the waste, the moisture content of raw sludge may vary from 90 to 99 per cent of the total weight of the sludge. This means that only 1 to 10 per cent of the sludge is solid material. Therefore, concentration of the sludge or the weight to be handled is proportional to the moisture content. If the moisture content is high, then there is more sludge to pump or truck away.

#### OBJECTIVES OF SLUDGE TREATMENT

There are three very important reasons for treatment of sludge prior to disposal, which are as follows:

- (1) To destroy or control sources and agents of disease and infection. Since raw primary sludge is an accumulation of settled waste from a raw sewage, it must be heavily populated with disease causing organisms which could be dangerous to health if it is not properly treated and disposed.
- (2) To reduce the volume of material to be handled. The total volume to be disposed of may be reduced by a significant amount if some of the water can be removed.
- (3) To reduce odours. Raw sludge is very odourous, and treatment may reduce this.

#### METHODS OF SLUDGE TREATMENT AND DISPOSAL

The following is a list of the methods of sludge treatment and disposal:

- (1) Digestion - biological treatment of sludge under controlled conditions.
- (2) Conditioning - elutriation and chemical conditioning (by coagulant aids).
- (3) Dewatering - by lagooning, on sand filter drying beds, by vacuum filtration, and centrifuging.
- (4) Vacuum filter dewatering followed by heat drying and incineration.
- (5) Wet oxidation
- (6) Tank truck haulage and disposal on land.

Digestion will not be discussed in this lecture as it will be covered in detail in other lectures throughout the course. A brief description of vacuum filter dewatering will be presented in this lecture to initiate the reader to the process, but it will also be discussed in detail in a future lecture.

Conditioning of sludge will be discussed in conjunction with the processes where it is applicable - particularly in vacuum filtering. It may also be used to prepare sludge for more rapid dewatering on sand filter beds or in a centrifuge.

### Sludge Lagooning

Lagoons or waste stabilization ponds are presently very popular as a method of treatment of raw sewage for small municipalities. A similar system is applicable to sludge treatment but it is not common in Ontario. As with the conventional ponds, a sludge lagoon must be located away from buildings because of odours. Even digested sludge has some odour which may not be appreciated at a garden party.

This method of sludge dewatering should be used for digested sludge only. It is not impossible to use a lagoon for raw sludge but it would have to be in a very isolated area because of strong odours and the danger to public health.



The method of operation is simple. Sludge is discharged into the pond daily or as required to remove it from the digester. The moisture in the sludge is removed by decanting, gravity drainage out of the bottom of the sludge into the ground, simple evaporation of water from the sludge, and transpiration (evaporation from plants).

Think of this as a large pond with sludge being added regularly. Some of the water rises to the top and it is allowed to run off through a weir gate. Some water is drained away into the soil below the sludge. A large portion of the water is evaporated into the atmosphere. And finally, some water is absorbed by plants growing on the sludge and some is evaporated from the plants themselves. However, the growth of plants, namely weeds, is to be discouraged.

The design retention time for a conventional waste stabilization pond is 120 days or 1/3 of a year. However, for the sludge lagoons the design retention time, or actually it is the cycling time, is the inverse or three years. It is a long term process and is based on the following time requirements:

1 year to fill the lagoon to a depth anywhere from 2 to 6 feet,

1.5 years to complete the draining of the sludge,

and 0.5 year of resting for the area after the dry sludge is removed.

This seems like a long time but some researchers argue that this is not long enough for drying - this is actually a short cycle they say.

The design factor commonly used is 1 to 1.5 acres for each 1.0 mgd of sewage treatment in a complete secondary sewage treatment plant. More area would be required if it was a small plant with perhaps only one digester. Thus, it may be seen that this method is only suitable for small plants and where land is cheap enough to allow the use of large areas for this method of sludge disposal.

Items to be considered in the design are as follows:

- (1) there should be more than one cell because of the long period required after a cell is filled and before it is ready for use again.
- (2) to avoid ground water pollution there should be at least 18 inches of soil between the bottom of the pond and the highest point of the water table in the ground.
- (3) the surrounding land should be graded away from the pond to prevent surface runoff from entering the pond.
- (4) the decanting weir must be opposite the sludge inlet pipe to the lagoon.
- (5) the sizing of the cells and the dykes around them. Wide dykes are required if a dragline is to be used for removing the dried sludge. This might not have to be considered if a bulldozer is to be used for this purpose.

The dried sludge removed from a lagoon, especially if the sludge was adequately digested first, is an excellent soil conditioner. It is a black colour and of a fine texture.

It has also been suggested that, in some cases, the lagoon would not be emptied but instead grass could be grown on it and a lawn would result for park use.

In summary, the disadvantages of this method of disposal could be:

- (1) land area requirements
- (2) odours and nuisance
- (3) pollution of ground water

The Research Division of the Ontario Water Resources Commission performed a study in 1964 on the use of lagoons for sludge dewatering. It was concluded that deep lagoons are not effective in producing a dry sludge. However, they are capable of producing a thickened sludge and thus may be economically feasible as a method of reducing sludge disposal costs.

### Sand Filter Dewatering

As the name implies, this is a bed of sand which is used to filter the sludge. In this case, only digested sludge can be applied to the bed as it releases its moisture the fastest. Raw sludge contains a large portion of fine material which can quickly clog the bed and also it does not allow the water to separate readily. In addition, oils and greases which are in raw sludge retard the drainage and could quickly plug the sand. The greases are broken up and partially destroyed in a digester. Also since raw sludge, if applied to a sand bed, would take so long to dewater, that insect attraction and breeding would be likely.

This method of sludge dewatering was very popular in the past for large and small plants. Frequently, the beds were covered by a glass building similar to a greenhouse to keep out rain and to speed drying by evaporation. But today, high labour and land costs now limit the use of this method to smaller plants.

The method of operation of sand filter beds can be described as follows:

Digested sludge is pumped from a digester onto a bed of sand supported by a bed of gravel with a system of tile underdrains. The dosing is done in one application and the sludge depth is between 8 and 12 inches. After the sludge has dried, it is removed and either used as landfill or a soil conditioner.

The design factors are as follows:

The coarse sand layer at the top should be 9 to 12 inches in depth and effective size of the sand should be 2 mm.

The supporting gravel layer which contains the open-jointed tile should be 6 to 12 inches in depth above the tile drains.

The walls around the bed should be water tight and extend 15 to 18 inches above the sand and at least 6 inches down into the sand.

The inlet pipe should be at least 12 inches above the bed because the depth of sludge applied may be up to 12 inches.

A splash plate should be provided to prevent erosion of the sand during filling.

The filtrate or water which drains through the tiles should be returned back to the sewage treatment plant processes because it may contain a high 5-day BOD.

The following table gives the approximate area required for exposed and covered sand beds to treat sludges produced in the different sewage treatment processes. The area may have to be increased or decreased for different climatic locations:

Type of Treatment	Area in square feet per capita	
	Open Beds	Covered Beds
Primary	1.00	0.75
Trickling filter	1.50	1.25
Activated sludge	1.75	1.35
Chemical precipitation	2.00	1.50

A solids-liquid separation takes place in the sludge. This is assisted by the gases entrained and dissolved in the digested sludge which tend to buoy up the solids. Thus the

liquid tends to go to the bottom and it is drained off through the sand to the underdrains. A major portion of the water is removed in one day. Then evaporation of the remaining water to the atmosphere is the most important. As seepage and evaporation continue, the sludge cake shrinks horizontally and cracks form in it. This accelerates evaporation as more area of sludge is exposed to the atmosphere.

It has been found that the total drying time to reduce the moisture content to approximately 50 per cent by weight is one to two weeks if the weather is favourable. The volume of sludge may be reduced by up to 60 per cent in this time. Naturally, the drying time depends on the amount of sunshine, rainfall, and relative humidity. A plant in Arizona would have much better drying times than here in Ontario. Also the prevalence and the velocity of winds affect evaporation.

The depth to which the sludge is applied affects the drying time. If the depth is too shallow, it dries quickly, but labour costs rise because there is more frequent cleaning required. If the dosing is too deep then the drying time is too long and the operator may run out of available bed space. Finally, when the sludge is dewatered to the desired moisture content it can easily be removed with spading forks or flat shovels. In small plants, wooden planks are laid on the bed and a wheel barrow is used to haul the sludge out of the bed area. However, in larger plants other methods have to be devised. These include:

- (1) concrete runways for trucks to drive onto the beds,
- (2) narrow gauge railway tracks for small dump cars,
- (3) monorail buckets which haul to the trucks,
- (4) saddlebag bulldozers,
- (5) front end loaders and
- (6) conveyor belts.

Some sand will be removed with the dried sludge each time that the bed is cleaned. It has been suggested that new sand should be added when the depth of sand has been reduced to one-half of its original depth. In any case, the depth of sand should not be allowed to become too shallow or there will be insufficient depth for filtering. It might also be a good practice to mix the old and new sand to make a uniform size distribution.

To assist in dewatering of the sludge, a coagulant aid may be used. This may decrease the time required for dewatering up to 50 per cent. Alum is frequently used at a dosage rate of 1 pound per 100 gallons of sludge. Lime may also be used but it could increase clogging of the sand bed.

More wet sludge should never be added to a bed of partially dried sludge unless it is an emergency. This would necessitate a much longer drying time for the new sludge as the water would have to drain through the previously applied sludge.

Weeds should not be allowed to grow on the beds. They may be removed by the use of herbicides or through the use of well washed sand.

The sludge draw-off from the digester should be flushed if it does not drain itself to prevent internal pressures of explosive gases produced by digestion in the line.

#### Vacuum Filter Dewatering

In this case, dewatering of sludge is obtained by a filter with a vacuum applied. Suction is normally thought of when there is a vacuum. This is the principle of operation in this case.

A drum with diameter and length in the range of 5 to 10 feet or more in each direction is rotated on an axle. It is covered with a media of some sort. The drum is emersed in a pan which holds the sludge to be dewatered. A vacuum is

applied on the inside of the drum by a vacuum pump located outside and connected by piping. As the drum turns through the sludge, the vacuum causes water in the sludge to be sucked into the drum and a layer of the sludge solids is drawn onto the outside of the drum.

The vacuum is continued as the drum rotates out of the sludge and into the atmosphere. This pulls more water away from the sludge leaving a moist mat or cake on the outer surface. Just before the portion of the drum being observed enters the pan or vat again the layer of dewatered sludge is scraped, blown, or lifted away from the drum. The dewatered sludge falls onto a conveyor belt or into a hopper. The filtrate water is returned to the sewage plant for treatment again as in the case of the sand filters.

There are various types of filter media which are available. In Ontario, only one type is commonly used. These are as follows:

- (1) Fabric covered-includes cotton, wool, felt, dacron, saran, and polyethylene. The synthetics are claimed to have longer life, greater yield in many cases, and the material is more easily cleaned.
- (2) String filters - this is a fabric covering but the sludge cake is removed from the drum by strings which pass around the cloth. Thus there is no air blower or scraper required. It is to be noted that the scraper is often called a "doctor".
- (3) Coil spring filters - this is the one most commonly used in Ontario. There are two layers of steel coiled springs placed in corduroy fashion around the drum. The spring layers leave the drum, are separated, and the cake is scraped off.
- (4) Travelling belt filters - this is a stainless steel woven wire belt around the filter.



The sludge has to be conditioned before it is filtered. This is done in:

- (A) elutriation tanks - this is a process often called washing of the sludge. Fresh water or plant effluent is added to the sludge in two or three times the volume of the sludge, they are mixed, settled, and the separated water is returned to the plant for treatment. The primary purpose of this is to change the alkalinity of the sludge.
- (B) Coagulation and mixing tanks - conditioning chemicals are added to the sludge which cause the solids to coagulate and thus the water will be released more readily when the sludge is filtered.

These tanks are placed in line before the filter to prepare the sludge before it enters the pan under the filters. The tanks do not have to be large because the conditioning time is short and very critical to the operation of the unit. Also conditioning must be done as a continuous feed.

The speed of rotation of the drum is quite slow - 2.5 to 4 minutes per revolution is usual. The cake thickness on the drum varies between 1/4 and 1/2 inch. The parameter used to specify the rate of filtering is pounds of dry solids per square foot of filter area per hour.

A vacuum filter can reduce the moisture content in a sludge from the 95 per cent range to approximately 75 per cent. This may not seem to be very much, but a look at these figures will show that this is a reduction of about 1/4 of the total weight of the sludge. This is significant when large volumes of sludge are being treated daily.

Vacuum filters can readily treat raw or digested sludge. They are most commonly used for raw sludge because they remove enough moisture to prepare the sludge for incineration or land disposal.



The factors that the operator of a vacuum filter is most interested in are:

- (1) good production yield from the filter,
- (2) economy of operation, and
- (3) a low moisture content filter cake.

To effectively obtain all these three objectives the operator must try combinations of the following variables:

- (1) Dilutions used in elutriation: to obtain the best solids separation and the maximum removal of alkalinity. This in itself can be a complicated trial and error procedure.
- (2) Coagulation: too long or too short a conditioning period can reduce the effect of the coagulating chemicals. Mixer speed is also a factor.
- (3) Chemical feed: many coagulants and filter aids have been used. Various combinations and feed rates should be tested to obtain the most economical and effective results.
- (4) Drum submersion and speed: various drum submersion depths and speeds must be tried. The combination of these factors producing the highest solids yield, along with desirable moisture removal, must be ascertained.
- (5) Filter media: the operator might experiment with various filter cloths if economics may allow.

The above operating factors may be summarized in more simple terminology. First, the dilution or the quantity of water added to the elutriation tank can be varied. Secondly,

the type of chemical added, the contact time, and the mixing provided in the coagulation tank can be varied. This is very critical to the process. Thirdly, the drum speed of rotation and its depth into the vat of sludge can have an effect. And finally, one type of media may be more efficient than another.

Proper care and maintenance of the filter are important. The following rules should be followed:

- (1) Wash the filter material well with spray jets after every period of use and remove the excess sludge from the pan.
- (2) Remove grease with a warm soap solution, if the material is clogged.
- (3) Remove lime encrustations with a dilute hydrochloric acid solution.
- (4) Adjust the scraper blade properly to prevent wear of the filter material.
- (5) Avoid excessive use of chemicals.

As for disposal of the vacuum filter cake, there are several methods available. It can be dried, incinerated, or used as a soil conditioner. However, extended use of the soil conditioner on one area of land may not be advisable as the coagulating chemicals may have an adverse effect on the soil.

One extremely important point to remember is that many plants require duplicate vacuum filter units. Unless there is considerable sludge storage, an operational problem might result when it is necessary to remove the filter from service for routine maintenance or there is an unexpected breakdown.

In comparison to sand filter beds, a vacuum filter requires less area, is independent of the weather, and it can treat raw sludge which eliminates the need for sludge digestion facilities. However, a vacuum filter is more costly to operate.

### Centrifuging

Raw sludge may be dewatered to a moisture content of 70 per cent by high speed centrifuging. However, the centrate or the water removed usually contains a high quantity of fine solids. The density of the solids is so close to that of the water that it may stay with the water rather than go off with the heavier solids.

The dewatered sludge may be dried, incinerated or used as a soil conditioner.

### Vacuum Filter Dewatering followed by Drying or Incineration

Drying and incineration of the vacuum filter cake are further methods of treatment and disposal. The filtered sludge may be dried to a moisture content of about 10 per cent for use as a soil conditioner or as an additive for commercial fertilizer. If it is desired to dispose of the sludge with the least volume of material to be handled, then it may be incinerated to an inoffensive ash.

These methods must be considered only for very large treatment plants because the costs of installation and operation are very great. Also considerable training and skill is required for the operators.

The purposes for drying sludge are as follows:

- (1) to reduce the volume of sludge. There is a considerable reduction when the moisture content is lowered from 75 per cent to 10 per cent.
- (2) to retain the fertilizing properties of the sludge.
- (3) to retain and improve its soil conditioning properties.
- (4) to destroy organisms capable of producing disease

and (5) to reduce odours in the sludge

The purposes for incineration are as follows:

- (1) to destroy all organic material.
- (2) to kill all organisms.
- (3) to control by burning all the gases released
- (4) to reduce the volume to a minimum
- (5) to produce a readily disposable material by the most economical means of disposal.

Drying of vacuum filter sludge may be performed by the following equipment:

- (1) rotary kiln dryers - this is a cylinder which rotates on an inclined axis. The sludge falls down in the cylinder while being mixed with hot (up to 700°F) gases rising in the cylinder.
- (2) flash dryers - sludge cake mixed with previously dried sludge is fed to a cage type mill where the sludge particles are dried almost instantly as they are dispersed and held in suspension in a stream of gases at 1100°F.
- (3) spray dryers - the sludge is sprayed into a vertical chamber where hot gases mix with it and evaporate the water.

Incineration is achieved by flash type incinerators, which are similar to the flash dryers mentioned above but the temperature is approximately 1600°F, and multiple-hearth furnaces where the sludge is burned to an ash.

The multiple-hearth furnace consists of a vertical cylinder lined with fire brick and containing a series of four

or more hearths one above the other. Dewatered sludge is fed to the upper hearth and is partially dried by the hot gases from the lower hearths. It is moved successively down to the next lower hearth by rotating plows or mechanical rakes until dried to a point where it will ignite and burn to an ash.

The incinerator has to be equipped with a smoke stack. Therefore, air pollution control facilities have to be included which prevent the discharge of odours, dust, fly ash, and soot.

Dried sludge from the rotary kiln is granular and may contain large clinker-like masses which require grinding for further use. The waste resulting from the flash and spray driers is a fluffy material suitable for fertilizer use.

The ash from sludge incinerators is usually disposed of by using it for fill. Where fill area is available close to the incinerator, the ash can be made into a slurry with water when removed from the ash hopper and pumped to the point of disposal. If the fill area is remote, the ash should be wet sufficiently to suppress the dust and transported by truck or other suitable means.

Design and operation of incineration units is quite complicated. Very few sewage plant operators will become involved in this and therefore these will not be discussed in any more detail in this lecture.

In conclusion, it may be stated that generally land-fill, using the filtered cake, would be more desirable than these expensive procedures of drying and incineration, except where the quantity of sludge is very great.

#### Wet Oxidation

The use of this method is similar to that of drying and incineration in that it is not normally used because it requires expensive equipment and must treat adequate quantities of sludge to justify the construction costs. Successful operation also depends on the maintenance of a continuous supply of homogeneous sludge of fairly uniform solids content.

One argument in its favour is that it can handle either raw or digested sludge. Vacuum filtering is not required first and an 80 to 85 per cent reduction of the BOD of the sludge is achieved.

This is a chemical reaction utilizing high temperature and pressures and oxidation of the organic material in the sludge is achieved by oxidation with oxygen obtained from air. The sludge is reduced to an ash. The liquid portion of the effluent carries the ash which may be removed by sedimentation in tanks or lagoons.

The process, known by the name of its inventor, F. J. Zimmermann, requires extensive high pressure equipment, but the system is self sustaining as far as heat is concerned.

#### Tank Truck Haulage

Many municipalities are using this method of sludge disposal. It is popular where homes are close to the plant or space is limited for lagoons or sand beds. As long as the distance to the dump site is not too great, it is a simple and economic procedure.

Both raw and digested sludges may be spread on land where adequate aging and cultivation is affected. Where an adequate aging period is not allowed the land should not be used for crops which may be eaten raw. At no time should either raw or digested sludge be spread on growing crops which may be consumed raw. Unless sludges are effectively heat dried they should not be spread on active grazing land. Forage crops which have been treated with sludges not rendered innocuous by heat drying should be cured before use.

With the exception of the nitrogen and phosphorous content in undigested activated sludge, the fertilizer content in sludge is small. Therefore, the greatest percentage of sludge products are classified as soil conditioners, and not fertilizers. Nevertheless, this material, whether termed as fertilizer or soil conditioner, can provide valuable humus and trace elements to the soil. The three main constituents required in commercial fertilizer are nitrogen, phosphorous and potassium. Nitrogen and phosphorous are available in good percentage in sewage sludge while potassium is generally available in amounts less than 1 per cent.

The type of treatment from which the sludge originates, as well as the nature of the raw sewage, have a great bearing on the value of the resultant sludge as a soil conditioner. In the order of value with respect to nitrogen content, undigested activated sludge is greatest with digested activated sludge, raw primary sludge, and digested primary sludge following in that order.

In purchasing a vehicle, the quantity of sludge to be removed must be known as well as the length of haul, the time an operator is available, and other uses for which the truck may be used. For small plants, finances will greatly limit the type of vehicle which may be obtained.

Sludge tanks which will be utilized for liquid sludge transportation should be constructed with an oval or round cross-section. Structural cracks will develop in the thin plate if a square design is followed. The use of twelve gauge high tensile steel plate will provide corrosion resistance and more than adequate strength. The use of a top operated valve, with the valve located in the tank itself, for the sludge discharge line will prevent freezing during winter operation. When a four inch gate valve is used, the pipe between the tank and the valve itself must be insulated and also provided with a heating element. The tank must also be constructed with adequate internal baffles, inspection and loading manholes, and vacuum relief valves on the top.

Sludge cake should, if possible, be handled in a dump box equipped with a water tight gasket on the rear gate. The sides should have more than normal freeboard allowing one cubic yard of volume for each ton of cake to be carried. A heavy duty hoist is advised to enable spreading with the box up while travelling over rough terrain.

When disposing of sludge great care must be taken to ensure that nuisances are not created. Common sense rules must be followed to prevent obnoxious odour complaints. When a municipality receives numerous complaints regarding refuse and sludge disposal, very restrictive regulations may be enacted.

Only very isolated dumping areas should be used for raw sludge and the applied material must be plowed in very quickly. Winter weather will prevent odours but it may be



difficult to work the sludge into the soil early in the spring and obnoxious odours might develop at that time. In general, raw sludge products must be very carefully handled. It might be advisable to dispose of raw sludge at a land fill project, where daily coverage can be provided.

Digested sludge is less odourous and therefore immediate coverage is not as important. Liquid sludge can be spread evenly and thinly. Where quick drying is possible, on sandy and elevated dry land, it may be disposed of close to homes. Nevertheless, great care must be taken that obnoxious odours do not carry to residences and furthermore, only well digested liquid sludge can be considered in this category.

Digested sludge cake must be handled more carefully. It is difficult to spread thin and therefore wet lumps of material may emit some offensive odours. If possible this material should be worked into the soil soon after spreading.

## CONCLUSIONS

In most of the methods discussed in this lecture, a point that should be noted is the per cent of moisture removed. A decrease of 10 per cent may seem to be a very small amount for the quantity of work and time involved. But over a period of years of handling large volumes of sludge, this may make a tremendous difference in the total volume handled. Consider the cost of a trickling filter system in comparison to a tank truck. Initially the truck is much cheaper, but after a few years of problems in hauling during the winter season and summer cropping times combined with long haulage distances, the filter may be much cheaper in the end.

A study performed in England produced the following conclusions:

- (1) It is desirable to thicken the sludge prior to sand bed drying because there is less water to be removed and therefore, an accompanying decreased drying time is required.



- (2) Vacuum filtration and heat drying are independent of weather conditions. However, they require considerable labour and are very expensive.
- (3) Tank truck disposal is final and cheap. But a moderate labour force is required which is significant in the holiday season.
- (4) Drying beds fall midway between other methods in total cost, and labour requirements are low. However, disposal of the dried sludge could be difficult and the large area required is their greatest disadvantage.

## CHLORINATION OF SEWAGE

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Chlorine is one of the commonest chemicals used in sewage treatment plants. In the following text the various uses to which it may be put will be discussed but before that a general description of the material itself is warranted.

The first point which must be stressed is that chlorine, particularly in its gaseous state is dangerous. This will undoubtedly be impressed upon you in your discussions of safety practices.

Chlorine (chemical symbol  $\text{Cl}_2$ ) when added to water forms free chlorine ion ( $\text{Cl}^-$ ) and acid.

It may be added as gaseous chlorine ( $\text{Cl}_2$ ) or as hypochlorite ( $\text{Ca}(\text{OCl})_2$ ).

In either form the results are similar - the release of a strong oxidizing agent which will produce the following results.

### DISINFECTION

The most important use of chlorine is for the disinfection of plant effluents. This is essential to protect water supplies and recreational areas in the vicinity of the sewage treatment plant. The amount of chlorine necessary to obtain a satisfactory reduction of bacteria will vary greatly with the kind of treatment the sewage has received. While the effluent from a well operated activated sludge plant or trickling filter may require only 2 - 3 ppm, a primary sedimentation plant, where prechlorination is necessary in order to obtain adequate contact time, may require a dosage of 40 ppm or more of chlorine. It is not practical in any case to specify a fixed dosage for chlorine but rather to require sufficient chlorine to give a specific

chlorine residual after an adequate contact time, e.g. a chlorine residual of 0.5 ppm after 15 minutes contact has been found adequate in most cases.

### ODOUR CONTROL

Odours in sewage treatment plants that are due to an anaerobic condition will usually respond to chlorination. In most cases the problem is to find the best point of application for the chlorine. In the case of primary clarifiers where the sewage has become anaerobic during the sedimentation period, the chlorine should be added to the incoming sewage. When the odour develops in the sewers due to a low velocity, the chlorine should be added far enough up the sewer so that it has adequate time to control the anaerobic condition before the sewage leaves the sewer.

Industrial wastes with high oxygen demand such as come from packing houses, canneries, milk plants, etc. will turn anaerobic very rapidly and if this type of waste is found to be causing odour it should be chlorinated before it enters the sewer.

In controlling odours it is not necessary to chlorinate to a residual. It has been found that a dosage of 40 - 60 per cent of the chlorine demand will give satisfactory control.

### BREAKDOWN OF CONCRETE AND MORTAR

The hydrogen sulphide that develops in anaerobic sewage can cause other problems besides odour. This gas is quite soluble in water and will dissolve in moisture that has condensed on the walls and roof of a sewer. It is then oxidized by the air and the sewer to sulphuric acid and will dissolve the cement from the concrete and mortar and allow them to crumble. Chlorine, of course, is the answer to this problem, as it will oxidize the hydrogen sulphide before it condensed on the surface of the concrete and will also control the organisms that produce the gas.

### AID TO SEDIMENTATION

Chlorination of raw sewage will improve the rate of settling in primary clarifiers. This is especially true when the sewage is anaerobic as it destroys the gas forming organisms and prevents the sludge from rising.

### BOD REMOVAL

Chlorine reduces the BOD of sewage in two ways. Some of the decomposable matter is oxidized by the chlorine resulting in a permanent BOD removal, other compounds combine with the chlorine to form chloro compounds some of which are toxic to bacteria and others are no longer broken down by bacteria. The BOD reduction will vary from 15 - 35 per cent depending on the condition of the sewage. Generally speaking the lowest reduction is obtained in fresh sewage and the highest in anaerobic sewage. A BOD reduction of 2 ppm for 1 ppm of chlorine is obtained up to the point where a chlorine residual is obtained. Beyond this point the rate of oxidation drops off.

### GREASE REMOVAL

Chlorination can be used ahead of a clarifier as an aid in grease removal. The chlorine will break the grease emulsions allowing the grease to collect in larger particles that are easier to remove by skimming.

### ACTIVATED SLUDGE

There are a number of ways that chlorine can be used to advantage in operating activate sludge plants. In some cases sludge bulking can be controlled by chlorinating the return sludge. This will require about 5 ppm of chlorine and should be continued until a satisfactory sludge index is obtained. Sometimes at the start of this treatment the effluent becomes quite turbid but this condition should clear within a day.

When waste sludge that is being returned to the primary clarifier tends to float, chlorination of this sludge will give better settling.

When an activated sludge plant is overloaded there are several points in the plant where chlorine can be added to reduce the load. It can be used ahead of the primary clarifier to reduce BOD and increase the amount of solids settled, or it can be added to the aeration channels to aid in oxidation, or then added to the final clarifier, it can be used to control biological activity and prevent floatation of the sludge. The best point to add the chlorine can only be determined by experience and varies from plant to plant.

When a plant has become anaerobic from breakdown or overloading, chlorination is the quickest way to return it to an aerobic condition. In this case, chloride of lime is more effective than chlorine gas, as the pH is always low when a plant is anaerobic, and the lime raises the pH while the chlorine corrects the anaerobic condition. Care should be taken that the pH is not raised to the point where calcium carbonate is precipitated as it tends to form scale on the diffusers and plug them.

Supernatant liquor from digesters also introduces a problem in activated sludge plants that can be relieved by chlorination. Due to the high chlorine demand of this liquor, dosages as high as 80 ppm or more may be necessary to give adequate control.

Some success has also been attained in cleaning air diffusers by feeding chlorine gas into the diffuser headers.

### TRICKLING FILTERS

Several methods of chlorination have been used to clear up ponding of trickling filters. It has been found that dry calcium hypochlorite sprinkled on the surface, or a solution of hypochlorite sprayed on the surface, will cause the slime growth that is causing the ponding to slough off. Another method is to feed chlorine to the sewage going to the filters until the slime growth is cleared. In this case, the

recommended chlorine residual in the sewage going to the filter varies from 1 - 10 ppm. Where ponding is a frequent problem it may be necessary to set up a programme of chlorination at regular intervals. In some cases chlorination as often as one night each week has been used.

Where slime growth has penetrated deep into the filter more drastic methods may be necessary, such as flooding the filter with a strong chlorine solution. This will result in the removal of all biological growth from the filter and a period of 5 - 6 weeks will be necessary to bring the filter back into good operating condition.

Filter flies can be controlled by chlorination but it does not eliminate them completely. The recommended dosage varies from 3 - 10 ppm.

Chlorine can also be used to control the odour that is characteristic of trickling filter plants.

Chlorination of trickling filters is usually carried out at night when the chlorine demand of the sewage is at its lowest. This results in a considerable saving in the amount of chlorine used.

#### SLUDGE THICKENING

In some plants, sludges, both activated or primary, are thickened before they are pumped to the digester or dewatered. Chlorine can be used here to control bacterial action and better settling and concentration is obtained. To do this it is necessary to maintain a residual of 1 ppm of chlorine in the supernatant liquor above the sludge.

#### STREAM PUTREFACTION

Chlorine can be useful in controlling putrefaction in a receiving stream. As stated earlier it is possible to obtain a BOD reduction as high as 35 per cent and also the chlorine slows up biological action, so that in some cases it is possible to carry the load to a point where there is

adequate dilution to take care of it. However, chlorination is not always an answer and on some small streams it just moves the nuisance area to a point further downstream.

#### CONTROL OF CHLORINATION

Due to the great variation in flow and strength of sewage, an accurate control of chlorine residual is impossible. In small plants it is suggested that the residual be checked each day at the time when it is known the maximum load is being received. This will assure of always having sufficient chlorine. In larger plants it will be worthwhile to adjust the dosage during the night when the flow and chlorine demand is much lighter. In very large plants automatic or semi-automatic chlorinators will be used and it is possible that dosage will be checked as often as every hour.

#### TESTING FOR CHLORINE RESIDUAL

There are three methods used in testing for chlorine residual:

- (1) ortho tolidine
- (2) starch iodide
- (3) amperometric

The ortho tolidine test is much the simplest but unfortunately there is too much interference in some sewages and a test cannot be made. In smaller plants we would recommend that the ortho tolidine test be used if it will give satisfactory results.

## BASIC ELECTRICITY

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### BASIC ELECTRICITY

The word electricity is derived from the word electrum, which in Latin means amber, because the first electrical discovery was made in connection with amber. Amber and lodestone both have strong attracting qualities. Electricity is an invisible force of nature which may be controlled under certain well known laws. An electrical law is a fact or set of facts which have been proven by experiment.

### THREE ELECTROSTATIC LAWS

1. When two unlike unelectrified bodies are rubbed together, one will take on a positive charge and the other, a negative charge.
2. When an unelectrified body comes in contact with an electrified body, it will take a charge similar to the electrified body (electro static induction).
3. Like charged bodies repel and unlike bodies attract each other. As most of us have had some experience with small permanent magnets, we know that like poles repel and unlike poles attract.

### THE ELECTRON THEORY

All materials are composed of atoms. An atom is a part of matter which may be divided into by electrical means. It is invisible. An electron is many times smaller than an atom. The atom consists of a positive centre or nucleus which comprises neutrons and protons and revolving around this nucleus are tiny negative electrons. The normal atom has an even balance of positive and negative charges.



## STATIC ELECTRICITY

Static electricity is electricity at rest in the form of charges. It may be produced by means of friction or induction. It is of very little commercial value, because it cannot be used for light, heat or power. It is used for experimental purposes and for testing insulating materials. A typical example of static electricity, which I am sure you have all come in contact with it when you cross a floor with a heavy carpet on it and you touch something metallic on the other side such as a doorknob, etc., you will get a slight tingle in your fingers.

## MAGNETISM

Magnetism is an invisible force of nature which seems to have always existed. The invisible force which exists between the poles of a magnetic is known as the magnetic flux, or lines of force. It is assumed to be always in motion, always in rotation. Lines of force lead at the North Pole of a magnetic and enter at the South Pole. First law of magnetism - like magnetic poles repel and unlike poles attract each other. Second law of magnetism - the force exerted between two poles of opposing magnets is inversely proportional to the square on the distance between them. Magnetism affects only magnetic metals, iron, steel, nickel, cobalt, etc. Nickel and cobalt are only fair attractions.

### Natural & Artificial Magnet

Natures magnet is lodestone. Artificial magnets are magnets made by induction, temporary, permanent, and electro-magnet.

### The Molecule Theory of Magnetism

The little molecules which make up magnetic metal are tiny magnets, which line up with their North Pole all in one direction when the metal is magnetized. A temporary magnet is made of soft iron and has the qualities known as permeability. Permeability is a measure of ease with which magnetism passes through a substance; a permanent magnet is made of hard steel and has a quality known as retentivity.

The Molecule Theory of Magnetism (continued).....

Retentativity is the ability to hold the molecules lined up.  
Reluctance is the opposition offered to magnetism.

Electro Magnets

An electro magnet is a coil of insulated wire wound on a soft iron core. The magnetism is produced by means of a current passing through the coil of wire.  
Electro Magnetic Induction: when a conductor or wire is moved through a magnetic field an electrical pressure will be induced into it. The voltage induced into the armature of a generator will depend on three things.

1. The number of turns in series.
2. The strength of the magnetic field.
3. The speed of the turning R.P.M.'s of the armature, will give the direction of the current flow.

When given the direction of the current, to find the direction of the whirls, place the thumb pointing the way the current is flowing and the fingers will give you the direction of the whirls. It is important to note that only the right hand is used.

ELECTRO MAGNETIC INDUCTION

Transformers

A transformer is a device used to increase or decrease A.C. Voltage. It consists of two separate windings on a laminated iron core. One winding is known as the high tension winding and low voltage. The high tension voltage winding has a greater number of turns and smaller wire. The primary side of the transformer is always connected to the source, the secondary side of the transformer is always connected to the load.

## ELECTRO MAGNETIC INDUCTION

### Transformers (continued).....

When the transformer is to be used for a step-up transformer, the low tension winding is used on the primary. On a step-down transformer the high tension winding is used on the primary. Transformers are 99.6% efficient in high voltage but they are only about 86% in lower voltages.

There is no electrical connection between the primary and secondary windings. Voltage induced in the secondary winding of a transformer depends upon the ratio of the number of turns to the number of turns on the primary winding, and the pressure applied to the primary voltage. Assuming transformer is 1000 V at 100% efficiency and 2 amps are applied, 10:1 step down, watts in the secondary step-down - 100 volts x 20 amps equals 2000 watts.

## CONDENSER

A condenser is a device used to store electrical energy. It consists of two conductors, the plates which are separated from each other by insulating material known as di-electrics. The charges in a condenser are stored on the surface of the di-electrics. A fixed condenser has a fixed capacity. Electrons move from a negative charge to a positive charge. Examples of static electricity are: lightning, around printing machines, etc. Method of moving static from such moving objects - the frame is grounded to earth. Another example of static electricity charge going to earth is on many a big fuel truck from which you will see a chain dragging which diverts any static electrical charge to earth.

### DYNAMIC ELECTRICITY

Dynamic electricity is electricity in motion or current; current is necessary to operate electrical equipment. It differs from static charges in three ways:

1. Its potential is lower.
2. Its actual quality is much greater.
3. It is continuous.

Three methods of producing dynamic electricity are:

1. Thermally by means of heat as by the thermo-couple in a pyrometer. When two unlike metals are joined together and heat is applied to the joint, an electrical pressure will be generated, which will cause current to flow when the circuit is completed.
2. Chemically by means of cells and batteries. When two unlike elements are immersed in a chemical solution (electrolite) a chemical action takes place which generates an electrical pressure and causes current to flow when this circuit is completed.
3. Mechanically by means of generators and magnets. When a coil of wire is moved through a magnetic field an electrical pressure will be induced into the coil, which will cause current to flow when the circuit is completed.

There are four effects produced by current:

1. Heating effects such as lamps, toasters, irons, etc.
2. Chemical effects such as in battery charging, electroplating and electrolysis. (the chemical decomposition of water or other substances by electricity).
3. Magnetic effect as in motors, buzzers, relays, annunciators, etc.
4. Physiological effect, the effect of current upon man and beast.

MOVEMENT OF DYNAMIC ELECTRICITY

Movement can be compared or illustrated by using as an example, a waterpiping system. Pressure on piping in a system either by elevated tank or pump compares with voltage or potential in electrical terms. It is actually the driving force. The rate of flow of water through piping compares with amperes in electrical terms, and the friction of piping which retards water flow compares with the resistance or ohms in electrical terms. So, in water and electricity, we have somewhat a similar action when they are in motion.

WATTS-OHMS LAW

These laws are very important. They are used to calculate the four fundamentals of electricity-pressure or volts-current or amps - resistance or ohms and power. They should be memorized letter perfect. Every electrical circuit consists of three factors: volts-resistance-current. Ohms Law teaches the exact relation between the three factors.

SERIES AND PARALLEL (See Figures 1,2,3 & 4)

A simple and practical electrical circuit consists of a source of energy, a load, and a means of control. A series circuit is where the current has only one path from the source all the way around and back to the same source. Current will follow the same rate through each device in a series circuit. Naturally, the voltage across each device will have to be added. A parallel circuit is where the current has two or more paths. Current in any path depends on the resistance in that path.

ELECTRICAL CONDUCTIVITY

As we know the atom is comprised of electrons and protons. Electrons have a negative charge and protons have a positive charge. In conductors, electrons move freely. Conductors are used in controlling and harnessing electricity in a given path or flow. Insulators, as you know, restrict the flow of electrons and this method of insulation protects against contact with live parts of the conductor and the better the insulation the higher the resistance against it. Thus, by means of conductors and insulators or insulation we can safely supply electricity to the systems and controls through switches and controllers, etc.

## SAFETY SWITCHES - BREAKERS AND CONTROLS

On all our electrical equipment we have controls and electrical protective devices used to safely control their operation. Fusing on electrical switches and current limitations on electrical breakers are the first line of protection for the equipment; their uses are simply to protect from any overcurrent above the equipment rating, that may damage same. So, do not put a higher rated fusing than the rating of the conductor or equipment can safely carry. When you do overfuse the known rating of equipment, you are making it prone to damage, through high current which may occur in your electrical system.

There are many fuses to choose from and they have different time limits for blowing. Some fuses are of the re-newable type; others are called one-time. All fuses should be pulled and installed with a proper fuse puller.

### Circuit Breaker

A circuit breaker may be described as a device for making and breaking a circuit under normal and abnormal conditions. As with fuses, the continuous current rating of a circuit breaker is determined by the rating of its trip element, which is the value at which the circuit breaker will trip automatically on overload or short circuit currents.

## MOTOR CONTROL CENTRES

If we inspect a typical Motor Control Centre in our plants, we note that the control centre is composed of a number of different motor control panels. Each panel is fitted with its own motor control components which are usually as follows:-

1. Moulded-Case Circuit Breaker
2. Motor Magnetic Contactor
3. Control Transformer
4. Control Fuse
5. Terminal Strip

Each of these individual motor control panels is designed to "Plug-In" to 3 vertical bus bars in the rear of the control centre to provide a three phase-550 Volt-60 cycle alternating current to energize the electric motor which is connected to that particular control panel.

If we trace the wiring inside the control panel, we note that the "Plug-In" three phase electrical supply is connected to the top or "LINE" side of the Moulded-Case Circuit Breaker. When the breaker is switched "ON" the 3 phase supply is fed from the "LOAD" side of the circuit breaker into the top or LINE side of the Motor Magnetic Contactor to 3 heavy stationary contacts. A two phase supply is also connected to the PRIMARY winding of the control transformer where the 550 volt supply is reduced to a safer control voltage of 120 Volt.

In turn, the 120 Volt Control Voltage is supplied through a small control fuse to Push-Button-On/Off stations, from whence it is forwarded when required, to energize a solenoid coil inside the Motor-Magnetic-Contactor. When the solenoid coil is energized, it exerts a magnetic pull on the moving or LOAD portion of the magnetic contactor and closes same.

As the magnetic contactor closes, the three heavy contacts which are connected to the 3 phase supply, make contact with 3 matching contacts on the moving portion of the contactor which has been pulled in by the solenoid coil's magnetic influence.

MOTOR CONTROL CENTRES (continued).....

The 3 phase 550 Volt Supply Voltage is now fed from the LINE side of the contactor to 3 terminals on the terminal strip, usually marked, T1, T2, T3.

From these 3 terminals, 3 motor cables are connected to the motor stator windings, so that now, a 3 phase 550 Volt 60 Cycle, A. C. electrical supply is connected directly to the motor windings to energize and turn the motor.

In the full operation of the motor control circuit as was just described, it would be necessary to continue pressing the "ON" button in order to energize the motor contactor solenoid coil. This is, of course, out of the question, so therefore, the motor contactor is fitted with auxiliary contacts to make a retaining circuit once the contactor is closed so that the solenoid is now supplied with electricity from another source and the press button can then be released.

When a "STOP" button is pressed, the control voltage to the solenoid is interrupted and the magnetic contactor opens to disconnect the 3 phase 550 volt supply from the motor windings to stop the motor. The contactor will remain "OF" until the "ON" button is again pressed.

MAINTENANCE OF MOTOR MAGNETIC STARTERS

Modern Motor Magnetic Starters have been designed to operate successfully for millions of successful operations, but like other types of moving equipment, are subject to wear and eventual failure or breakdown.

The maintenance man must anticipate such ultimate failure, and make the all important repairs or replacements ahead of the estimated time of failure.

There are certain things that must be inspected weekly, others monthly, and yet others quarterly or every six months.



MAINTENANCE OF MOTOR MAGNETIC STARTERS (Continued).....

A check list should be drawn up of the various points to check on an average motor contactor or control, as follows:-

1. Remove any dust or dirt by blowing or vacuuming.
2. Check for overheating or loose connections.
3. Check for friction or binding of moving parts.
4. Check contacts for wear and contact pressure.
5. Check control voltage to solenoid coil.
6. Check ARC chutes (if any) for wear or breakage.
7. Check flexible shunts for burning or breakage.
8. Check auxiliary devices such as push button stations etc., and clean where necessary.
9. Test operate the starter on control.

In general, good maintenance of motor starting equipment requires a good systematic program of steady inspection. With properly designed equipment, the frequency of inspection will depend on the normal wear and tear on the equipment. Experience will soon indicate the equipment subjected to severe service, and which will of course, require more frequent inspection.

All maintenance personnel should be thoroughly trained and supplied with up to date wiring and schematic diagrams, also operation and sequence manuals. The maintenance man should be trained to make fast, thorough inspections and safe temporary repairs if it is going to take too long to make permanent repairs. Permanent repairs can be made at a more opportune time when the equipment can be spared from service.

Reports of troubles must be made out, and complete records kept of all maintenance and inspection.

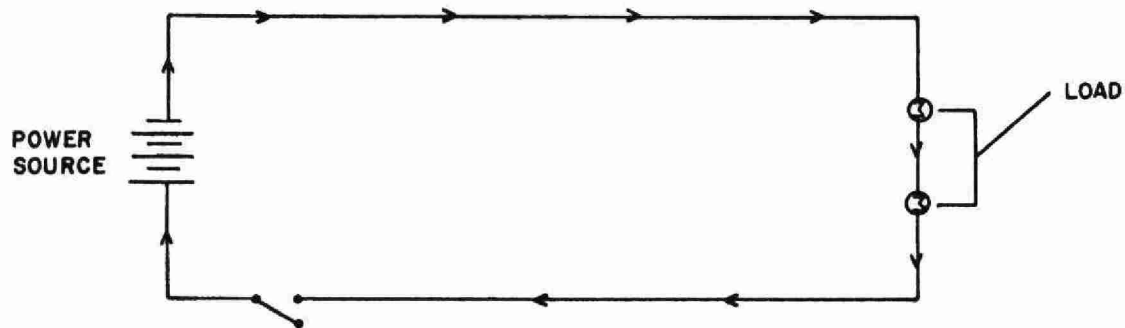
An adequate supply of renewable parts should be available, such as solenoid coils, spare contacts, etc. Parts that frequently require renewal, are generally inexpensive and easy to obtain from the manufacturer of the equipment.

ON FIRST AID

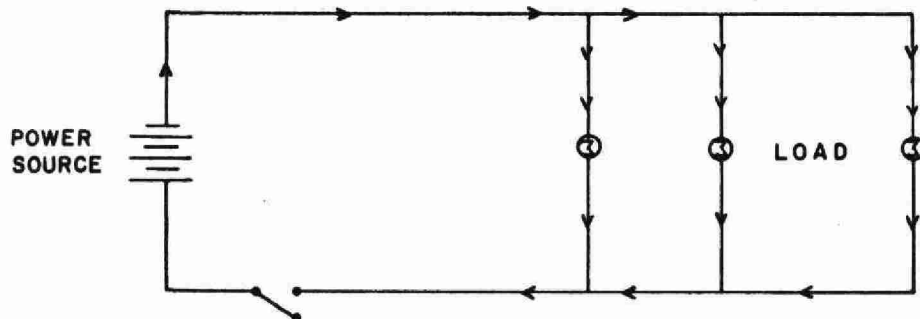
All personnel shall have some training in first aid. The knowledge of knowing how to employ artificial respiration is a must. For if a victim received a severe electrical shock he is sometimes knocked unconscious and it is of the utmost importance to use this method to revive him.

If the victim cannot let go of the electrical conductor, throw the disconnect switch. If this is not possible use something like a dry stick to push him away from the electrical conductor. Once again, I stress the use of electrical safety gloves on the site and once again please be careful. We like to see you around.

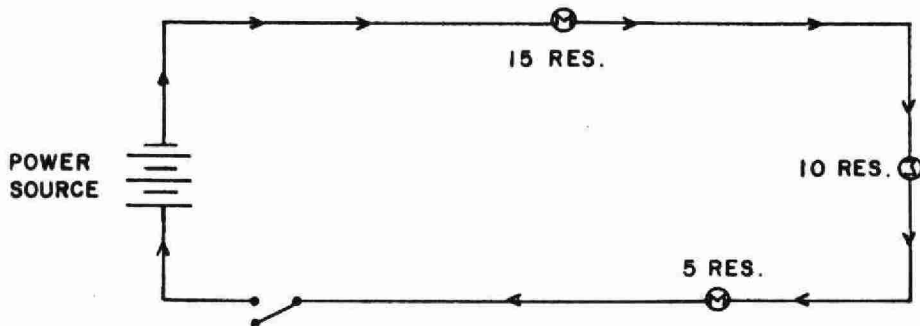
### SERIES CIRCUIT



### PARALLEL CIRCUIT

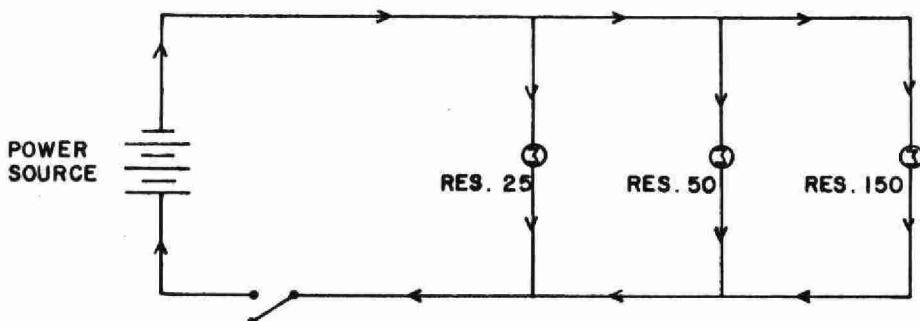


### SERIES CIRCUIT



TOTAL RES.  
 $15 + 10 + 5 = 30 \text{ OHMS RES.}$

### PARALLEL CIRCUIT



$$\frac{1}{25} + \frac{1}{50} + \frac{1}{150} \text{ RES.}$$

$$\frac{6 + 3 + 1}{150} = \frac{10}{150}$$

$$\text{RECIPROCAL } \frac{10}{150} = \frac{150}{10} = 15 \text{ OHMS}$$

LABORATORY CONTROL AT SEWAGE TREATMENT PLANTS

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INTRODUCTION

A sewage treatment plant like any piece of machinery must be properly operated if it is to produce optimum results. A mechanic performs certain tests on an automobile to ensure that it runs properly and to diagnose and intercept problems. A doctor must perform tests to diagnose a disease or to anticipate an illness before it becomes too far advanced. Similarly the sewage treatment plant operator can perform certain tests to determine how well the plant is operating, anticipate problems before they become too pronounced, or to diagnose existing problems.

There are, of course, many tests which can be performed depending on the amount and sophistication of the equipment available and the experience and time of the operating staff. Laboratory control under the scope of this paper will be limited to those tests which can be performed regularly at the plant itself, by the operator. Other necessary tests can be performed on a less frequent basis by the OWRC laboratory.

RECORDS

An important factor, often overlooked, yet of extreme importance, is the recording of the data resulting from the daily operational tests. By keeping records of plant test data, patterns in sewage quality can be established and problems can be anticipated before they become critical. Evaluation of plant performance as outlined by records of the daily operational tests can figure prominently in decisions regarding the need for, and extent of, plant enlargement. Lastly, by recording and interpreting the results of the operational tests regularly, the operator can gain a deeper insight into the operation of the plant, the processes involved and in turn make his job more interesting and challenging.

## SOLIDS DETERMINATION

In the practical operation of sewage treatment plants, the settleability of the sludge is an important factor. Variation of the mixed liquor concentration is the most flexible method of controlling activated sludge quality. By increasing or decreasing the amount of sludge carried, the food to micro-organism ratio can be controlled and maintained at the value which gives the best operating balance.

To control the mixed liquor loading, it is necessary to measure the suspended solids in the aeration tank and the settleability of the mixed liquor. This can be done at the plant by means of the centrifuge test and the thirty minute settling test.

### Centrifuge Test

The total dry weight of the suspended solids can be determined by filtering, heating and weighing in a laboratory, or from a centrifuge calibration curve. The laboratory method of course, provides the most accurate determination of suspended solids value. However, this procedure is long and involved, and requires rather sophisticated equipment not often available at most treatment plants. The centrifuge test has the advantage that it is easy and quick to perform and does not require much equipment other than a centrifuge which is readily available and inexpensive.

The standard centrifuge used at sewage treatment plants is equipped with two 15 ml graduated tubes. The test is carried out by filling both tubes up to the mark with a sample from the aeration tank effluent. The centrifuge is then turned on and operated at a speed in the order of 1500 to 1800 rpm for three to five minutes. Whichever combination of centrifuge speed and time is used, it is very important for uniform results that the centrifuge is always operated at the same speed for the same length of time.

It is also important that the sample is well mixed and the 15 ml tubes are filled in the same manor each time the test is performed. The samples should be collected from the same point in the aeration tanks at the same time each day.

To use the centrifuge test in plant control, it is necessary to have available a centrifuge vs suspended solids graph. Since sewage characteristics, loading conditions, and flows vary at all plants, the mixed liquor suspended solids characteristics will also vary at each plant. Therefore, it is advisable to prepare a specific graph for each specific plant.

This is done by collecting a different number of duplicate mixed liquor samples at different times, under different loading conditions, and determining the suspended solids by weight in the laboratory and by volume utilizing the centrifuge. The suspended solids by weight can be determined by sending the sample to the OWRC laboratory for analyses. The test results from each sample are then plotted on graph paper, and a line drawn to best approximate the plotted points.

Once this graph has been prepared the suspended solids value for subsequent samples can be obtained by merely performing a centrifuge test on the sample of mixed liquor and reading the corresponding value for suspended solids off the plant graph.

A typical centrifuge vs suspended solids graph is appended.

#### Thirty Minute Settling Test

This test is performed on a sample of the mixed liquor from the effluent of the aeration tank. The sample should be taken with as little agitation as possible. The test procedure consists of gently filling to the mark, a 1000 ml graduated cylinder. The contents of the cylinder are allowed to settle for thirty minutes and the volume occupied by the settled sludge is read off.

To merely conduct a settling and centrifuge test however, is not sufficient, as there must also be some knowledge of the density of the sludge. The relationship of volume to weight, or density is important in determining the condition of the sludge.

The sludge volume index is the volume in millilitres (ml) occupied by 1 gram (gm) of sludge after settling for thirty minutes. The formula for making the calculation is as follows:

$$SVI = \frac{\text{per cent settleable solids (thirty settling tests)} \times 10,000}{\text{ppm suspended solids (aeration tank)}}$$

The sludge volume index expressed as per cent solids is the sludge density index.

$$SDI = \frac{100}{SVI}$$

The level at which these values should be maintained and their significance in other operations will be discussed in detail by other lecturers. In general, bulking sludge that will not settle and is not suitable for return to the aeration tanks will have a high SVI, (200 or even higher). A low index of 40 would give a fast settling sludge, however, clarification is generally not the best at these low levels. An index of around 100 would be average.

### Frequency and Testing

The above tests should be performed on a minimum of at least once daily and preferably in the afternoon. In order to have a consistent correlation of results they should be conducted on samples taken from the same place at the same time each day. However, interesting differences can be noted if the tests are performed several times during the day rather than only once. It is suggested that on a few occasions the tests be made throughout the day at one hour intervals and the results recorded and plotted.

## DISSOLVED OXYGEN TEST

### Interpretation

The breaking down or decomposition of the organic solids in sewage can proceed in either of two ways.

1. In the presence of a supply of oxygen dissolved in the accompanying water, known as aerobic decomposition.
2. In the absence of oxygen or, as it is termed by anaerobic decomposition.

The end products of both processes are generally similar, in that stable, inorganic, substances result, which are not subject to further breakdown. However, during the process there are created considerably different conditions. In the



anaerobic or septic process foul odours such as  $H_2S$  (hydrogen sulphide) are created and the sewage has an unsightly appearance. When the breakdown occurs in the presence of oxygen, these unpleasant conditions do not occur and the reduction of organic matter continues in a more orderly manner.

When sewage, raw or treated, is discharged into a stream there is a drop in the dissolved oxygen content of the receiving water. Depending on the use of the stream, the level to which the dissolved oxygen drops is very important. The following table will give some guide as to the dissolved oxygen required for different types of streams.

<u>Stream Use</u>	<u>Necessary Level of Dissolved Oxygen</u>
For game fish	above 5.0 ppm
For coarse fish	above 3.0 ppm
To prevent nuisance conditions	above 0.0 ppm

These levels should be present under maximum conditions which generally occur at night or early dawn, when the dissolved oxygen in the stream is at its lowest value.

In raw sewage the dissolved oxygen level will vary depending on the existing conditions. The level will decrease, with heat as during the summer, as the flow in the sewers decreases and deposited solids in the sewers become septic, or as the travel time to the plant is increased, i.e. an extension of the sewer system. The oxygen level will rise as the flow increases due to storm water flow or ground water infiltration. Where sewer grades are good, a dissolved oxygen level of 4.0 to 6.0 ppm is common for average municipalities. In some areas however, such as Kent and Essex Counties, where the sewer grades are at a minimum because of a very flat terrain, it is not uncommon in the summer to have raw sewage with a dissolved oxygen content below 1.0 ppm.

The operator should take enough dissolved oxygen tests on the raw sewage at his plant to establish trends for the various seasons and weather conditions. Variations in the established patterns should be investigated.

In the activated sludge process, a dissolved oxygen level above 2.0 ppm and generally below 5.0 ppm should be maintained in the aeration tanks. It sometimes is not possible to



maintain the minimum level immediately adjacent to the inlet. The necessary level of oxygen to be maintained at the inlet will depend to some degree on the efficiency of the sludge collection and recirculation from the final settling tank. That is, where sludge remains for long periods of time in the final settling tank it will be necessary to have a higher oxygen content in the aeration tanks. This will reduce the possibility of septicity in the recirculated sludge. When too much air is added the sludge becomes nitrified, gas is produced and a poor settling floc results.

The amount of oxygen that can be dissolved in water varies with temperature. At a temperature near freezing, water will contain 14.5 ppm oxygen at 100% saturation, whereas at 60°F it will contain only 9.2 ppm of oxygen, at 100% saturation. It is therefore, important to take temperature readings at the time of the test. The test result can either be given as parts per million or per cent saturation.

A number of different methods have been developed for determining the dissolved oxygen content of sewage. The method selected for use must be one which will produce accurate results and eliminate the effect of any interfering materials present. Most tests are a modification of the Winkler Method. The one most frequently used in sewage treatment plants is the Alsterberg modification of the Winkler test. This test as well as the various modifications to compensate for interfering substances are all outlined in "Standard Methods For The Examination Of Water and Waste Water" prepared and published jointly by the A.P.H.A., AWWA., and the WPCP.

A simpler test for measuring dissolved oxygen is by the Miller Method. This is reasonably accurate except at the lower levels, i.e. around 1.5 ppm. At this value it generally gives a higher value to the dissolved oxygen reading.

To measure the dissolved oxygen content in the aeration tank the test is performed on grab samples and must be done at the time of sampling. Extreme care must be exercised in collecting the sample and carrying out the test to make sure that oxygen is not artificially introduced into the sample.

Another method for measuring dissolved oxygen levels which is becoming more prominent is through the use of the dissolved oxygen probe. In recent years a number of variations of the dissolved oxygen probe principal have been developed. These all consist essentially of an electrical method for providing

a direct reading of the dissolved oxygen level simply by insertion of a probe into the liquid and measuring the associated electrical current increase or decrease in a polarographic or galvanic probe. However, there are a number of problems with the use of this device due to the need for constant cleaning and calibration of the equipment and associated problems. Temperature also can severely affect readings. However, with advances in technology this will probably become a common method of measuring dissolved oxygen in the near future.

Where facilities and personnel permit, testing should be performed daily. Tests should be made on the raw sewage, plant effluent, aeration tank effluent, and return sludge. In smaller plants these tests can be performed less frequently once a pattern is established.

The Rawson nomogram for obtaining oxygen saturation values at different temperatures is appended to this lecture.

### CHLORINE RESIDUAL

Chlorine is used at sewage treatment plants for the disinfection of effluent, odour control, to reduce bulking in activated sludge plants and control the development of flies in trickling filters.

Some organisms in sewage can survive even complete treatment processes ; chlorine should be added to the final effluent to kill these organisms and check the spread of disease. This is particularly important in areas where the downstream water is used for drinking purposes, shell fish culture and recreational activities.

Residual chlorine may exist in one of two forms; either free residual chlorine, i.e., hypochlorite ions, or as combined residual chlorine, i.e., in combination with ammonia as chloramines or with certain nitrogenous compounds as organic chloramines. There are large numbers of chlorine absorbing material in sewage, therefore, free chlorine is seldom found.

To kill organisms with chlorine it is necessary to provide both a definite concentration of chlorine and to expose the organisms to this for a length of time. The Commission's requirements are that there be a chlorine residual of 0.5 parts per million after 15 minutes contact between the chlorine and the sewage.

The amount of chlorine applied to produce the above residual varies with different conditions and sewages. The following is an indication of the dosages which may be needed to produce a residual of 0.5 ppm.

<u>Type of Treatment</u>	<u>Chlorine Dosage</u>
Secondday treatment effluent	5.0 ppm
Primary treatment effluent	15.0 ppm
Raw sewage	25.0 ppm

The chlorine feed rate for an effluent will vary as to the flow and the quality. More chlorine will have to be applied as the flow increases and as the quality of the effluent deteriorates. Therefore, it is necessary to take frequent residual tests throughout the day until the operator establishes a definite pattern. It then may be necessary to only take one or two tests each day. In any case, an adequate residual should be maintained at all times.

There are various methods of testing but the one that is most frequently used is the orthotolodine test. Coloured solutions can be made up for this test but a more satisfactory method is to purchase the permanent colour disc type of comparators.

Sometimes interfering substances affect the orthotolodine test. In that case, the starch iodine test can be performed or an amperometric titrator can be used. All of these tests are outlined in "Standard Methods For The Examination of Water and Waste Water".

#### pH (HYDROGEN ION CONCENTRATION)

The pH is a measure of the hydrogen-ion concentration of a liquid. The higher the concentration, the lower the pH. It will vary from 1.0 to 14.0 with 7.0 being the pH of a neutral solution. Values greater than 7.0 are found in alkaline solutions and those less than 7.0 are found in acid solutions.

This test is important because it is an aid in controlling the operation of sewage treatment plants, although it has no sanitary significance and has little bearing on the strength of sewage. It is of most value in determining the condition of sewage and sludge.

The pH value of raw sewage may give valuable information regarding the presence of trade wastes. Strong alkaline reactions, above pH 8.4 may indicate the presence of excessive quantities of laundry waste or a discharge from some industry employing alkali. Intense acid reactions below pH 6.0 may indicate metal pickling wastes or possibly the discharge of brewery or distillery slop.

Close regulation of the pH value is necessary in the control of biological digestion. Optimum conditions are usually found from pH 6.8 to 7.4. Values much below pH 6.8 indicate acid conditions and in such instances digestion is usually accompanied by foaming and scum formation. Values greater than pH 8.4 may prevent proper growth of biological forms and preclude adequate digestion.

The pH of fresh, raw, domestic sewage normally ranges between 7.0 and 7.6. The pH of septic sewage will be lower.

### Testing

(a) The glass electrode method is more accurate than colour comparison. However, the equipment required is more expensive.

(b) The colour comparison method is reasonably accurate. In any case, the relative values obtained by one operator should be quite accurate and with experience the efficiency of operation can be related to different values. The permanent colour discs are preferable to the coloured liquids as there is generally less fading of colours.

The pH of raw sewage should be measured periodically on grab samples to establish the normal range. Tests should then be made whenever an unusual waste is seen or suspected.

The pH of the sludge should be determined about twice each week under normal conditions. More frequent observations should be made if loading rates are changed or unusual conditions develop such as the fall off of gas production.

### TEMPERATURE

Temperature readings should be taken frequently enough to establish patterns for various seasons and times in the day. The detection of a sudden drop in the temperature of sewage should

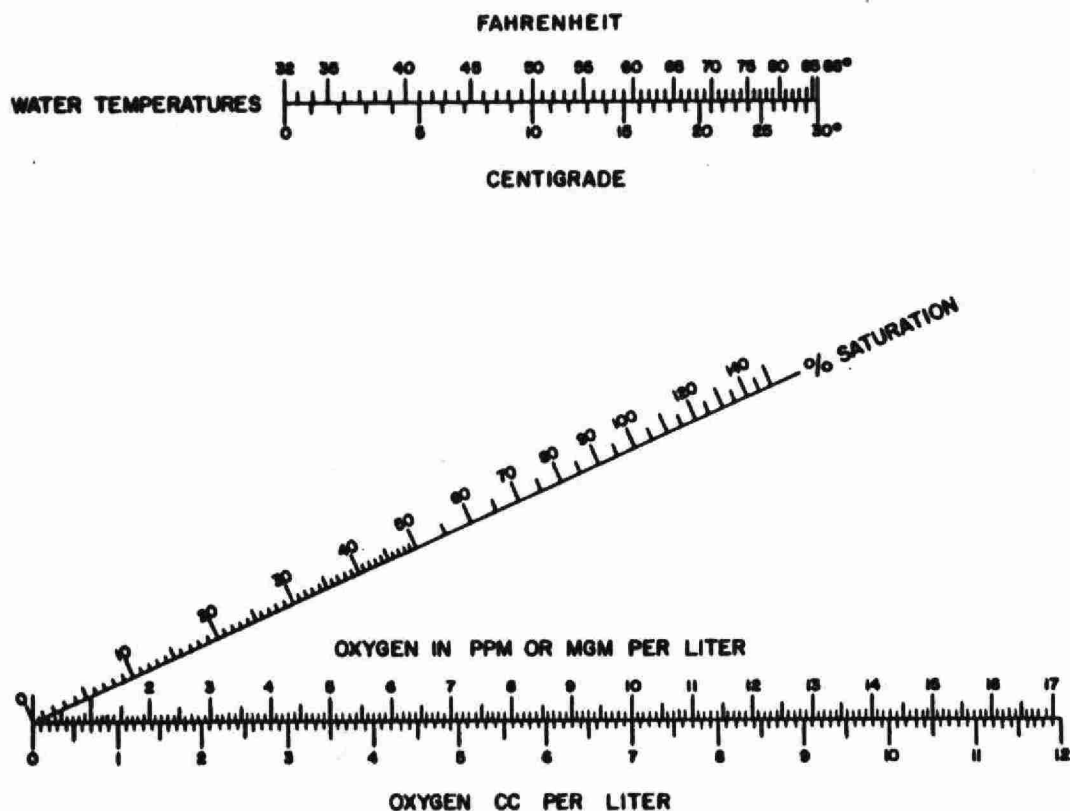
lead the operator to investigate such possible causes as infiltration of cold ground water or surface water. This might enter the system through direct connections or sewer leaks. A significant variation in sewage temperature would be accompanied by a variation in viscosity of the sewage, hence the settling characteristics would be affected. As the temperature of the waste increases, the viscosity decreases and sedimentation is improved. Biological activity, the reason sewage decomposes, is a function of temperature and time. As the temperature increases from 45°F to 105°F the bacterial activity increases. The temperature of sewage is normally a few degrees higher than the water supply of the community.

The only control on temperature in the plant is in heated digesters. These are generally maintained around 90°F. Recording charts are generally installed for recording this temperature.

There are many good quality thermometers on the market. Temperature readings should be taken at least daily.

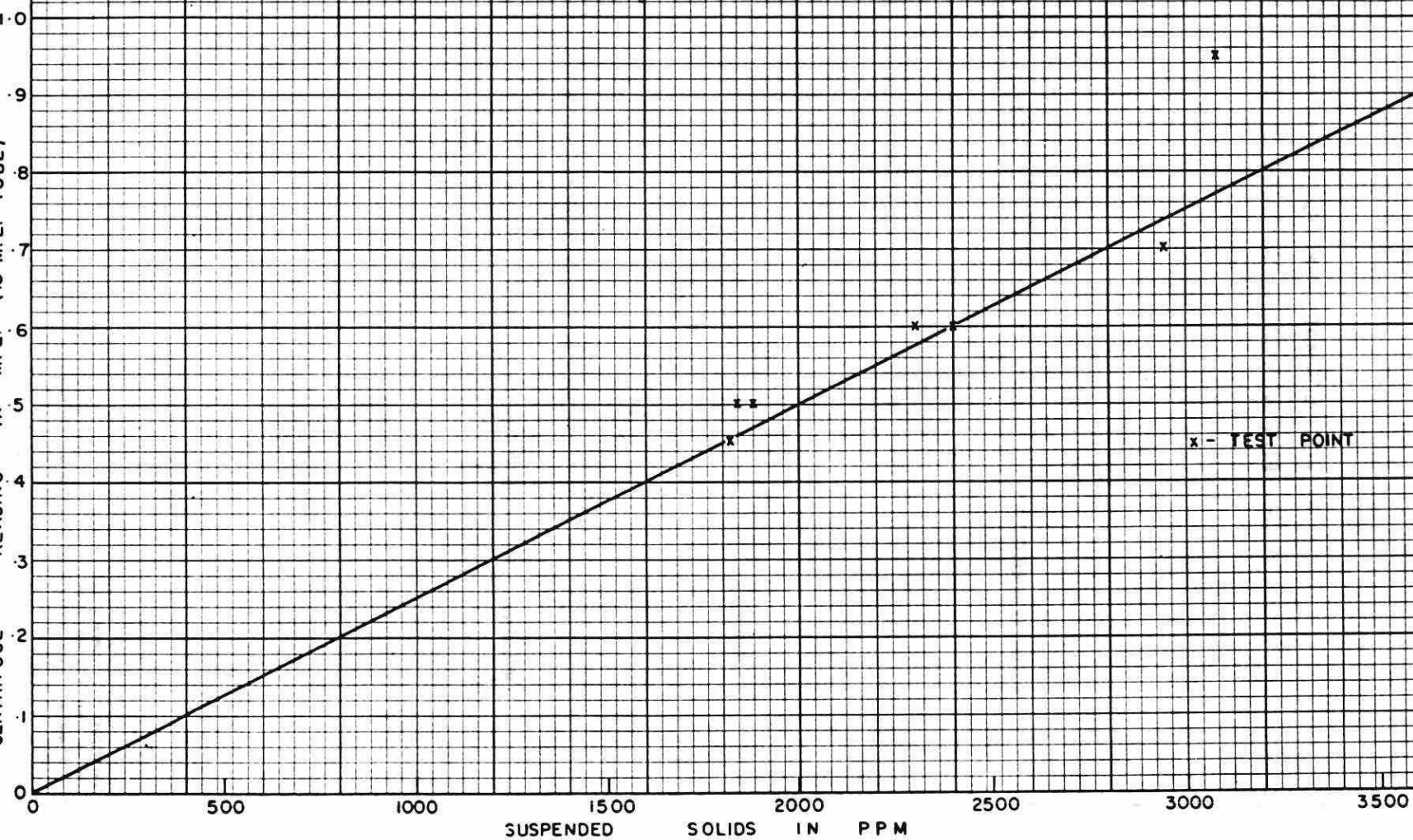
# RAWSON'S NOMOGRAM FOR OBTAINING OXYGEN-SATURATION VALUES AT DIFFERENT TEMPERATURES

- FOR NORMAL PRESSURE (760 mm.) AT SEA LEVEL
- FOR NORMAL DISSOLVED SOLIDS (LESS THAN 1000 p.p.m.)





SUSPENDED SOLIDS CENTRIFUGE CURVE  
(5 MIN.)



BOILERS AND HEAT EXCHANGERS  
(Operation and Maintenance)

J. F. Scheffers  
Division of Plant Operations

During this and subsequent lectures we will discuss boilers, heat exchangers and associated equipment their mode of firing and operation. Due to the time allotted us we are only able to go into the different subjects rather briefly but I will try to give those of you that are not familiar with the subjects, a sufficient understanding of the operation and maintenance of the various parts of a boiler. I would advise you to take notes because at the end of the course, questions on this lecture will appear on your examination paper.

WHAT IS A BOILER?

A boiler is a pressure vessel in which the potential energy in the form of oil, gas or coal is transformed into heat energy which in turn is used to heat water or produce steam. Let us define a couple of expressions first.

A pressure vessel is a closed tank which is placed under pressure by means of water, steam or air on the inside by an external supply fed into the tank. Potential energy is the force which is stored in a mass or substance in rest. An example is air under pressure in a tank, it does not do anything until a valve is opened and the air rushes out.

HOT WATER BOILERS

In this type of boiler we raise the temperature of our town water supply which is between 40° and 60° Fahrenheit to anywhere between 160° and 230° Fahrenheit, depending on our heating requirements. This hot water is used to heat our buildings and digesters, which require heat for proper digestion. The name, hot water boiler is significant. It designates the type of boiler



we are dealing with. Basically different to a steam boiler, a hot water boiler is filled right up with water and forms a complete closed system with the rest of the heating system or heat exchanger. Water leaves the boiler, circulates through the system and returns to the boiler for reheating. The difference between outlet and return temperatures should be approximately 40° Fahrenheit.

A steam boiler however is only partially filled with water and room is left in the boiler above the water level for the steam to accumulate in and to be withdrawn from the boiler to be used elsewhere. We will not discuss the steam boiler here any further, because only a few units are in operation within the Commission's plants and these are of the low pressure type.

Let us have a look at how we put a hot water boiler into operation. First of all we have to fill it. This is simple enough. We have a make up water valve of the pressure reducing type in tandem with a safety valve. This is mandatory by-law. A make up valve is a valve which connects the boiler with the town water supply and reduces the town pressure to approximately 12 p.s.i. Directly following this valve we have a safety valve installed to prevent excessive pressure in case of reducing valve failure. Most times this valve train has a by-pass valve installed as well to accommodate faster filling and to be used if repairs to the make up valve are necessary during operation. If you do not have a by-pass I would advise you to have one installed.

#### FILLING THE BOILER

We are now ready for filling. Open the valves A and D as marked in Figure 1. We also have to open a vent valve somewhere in the system. This vent valve may be a bleeding valve on a radiator or any other valve located in the system, open as high as possible. We have to let the air escape out of the system in this manner to assure ourselves that the system is completely

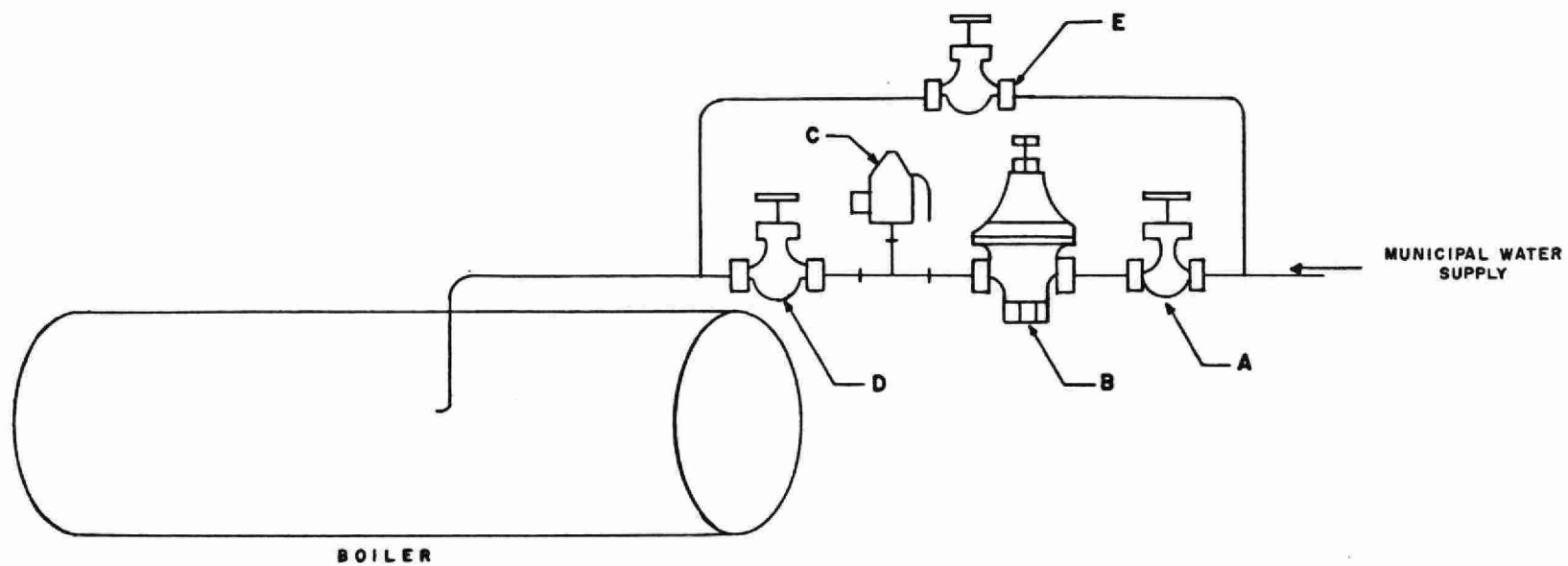
filled with water. The moment water starts escaping from this vent valve we close it off. We then let the pressure build up by means of the pressure reducing valve B (Figure 1) which is factory set to shut off at a predetermined pressure, this is usually 12 p.s.i. When this pressure is reached, do not touch the valve train anymore. Valve A and D should be opened and by-pass valve E should be closed (Figure 1).

### CUSHION TANK

There is one other important point we have to watch before we can put the boiler into operation. That is our cushion tank, (Figure 2). This is the cylindrical tank which is found often suspended from the ceiling above the boiler. This tank has only one pipe connection with the boiler and no valve should be installed in this pipe connection. This cushion tank must always be in open connection with the boiler as a valve in the line could accidentally be shut and thereby defeat the purpose of the tank. The tank must have a drain valve and a sight glass to determine the water level. The cushion tank must be absolutely air tight.

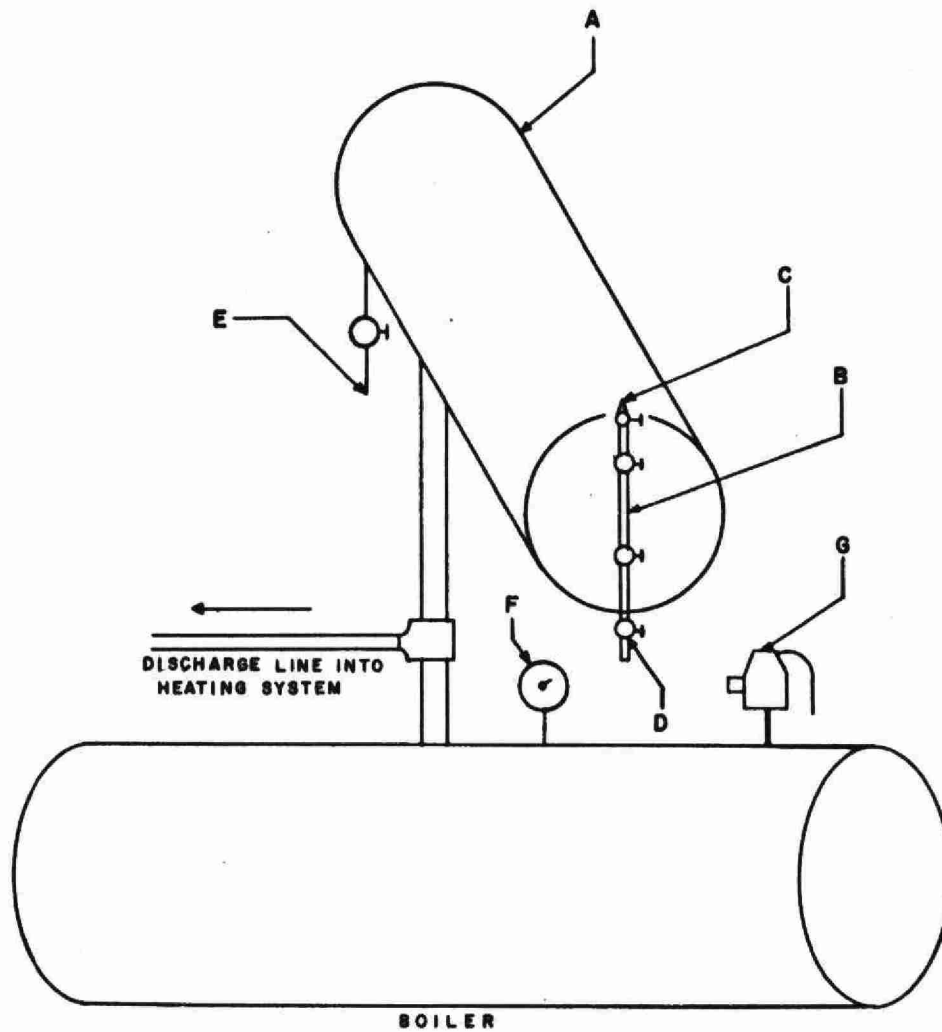
When water is filling up the system, air is trapped in the top half of the tank. This air will act as a cushion when the pressure increases due to the heating of the water. When water is heated it expands and this expansion causes the pressure to increase. If the whole system was absolutely full with no provision for expansion, the pressure would rapidly rise to a very high level, because water cannot be compressed. The air in the cushion tank will absorb this expansion. The air is compressed instead of the water and since air is easy to compress it prevents a build up of high pressure. When the boiler is up to pressure but still cold, the water will show about half way up the sight-glass and when the boiler is hot it will be slightly higher. If the level becomes too high in the cushion tank we must drain some water out of the tank but, if we do this we must also admit air through the little pet cock on top of the glass. If we do not admit air into the tank while draining we would create a vacuum, and the moment that we open the water valve the tank would fill up to the same level.

FIG. - I  
MAKE UP WATER VALVE TRAIN



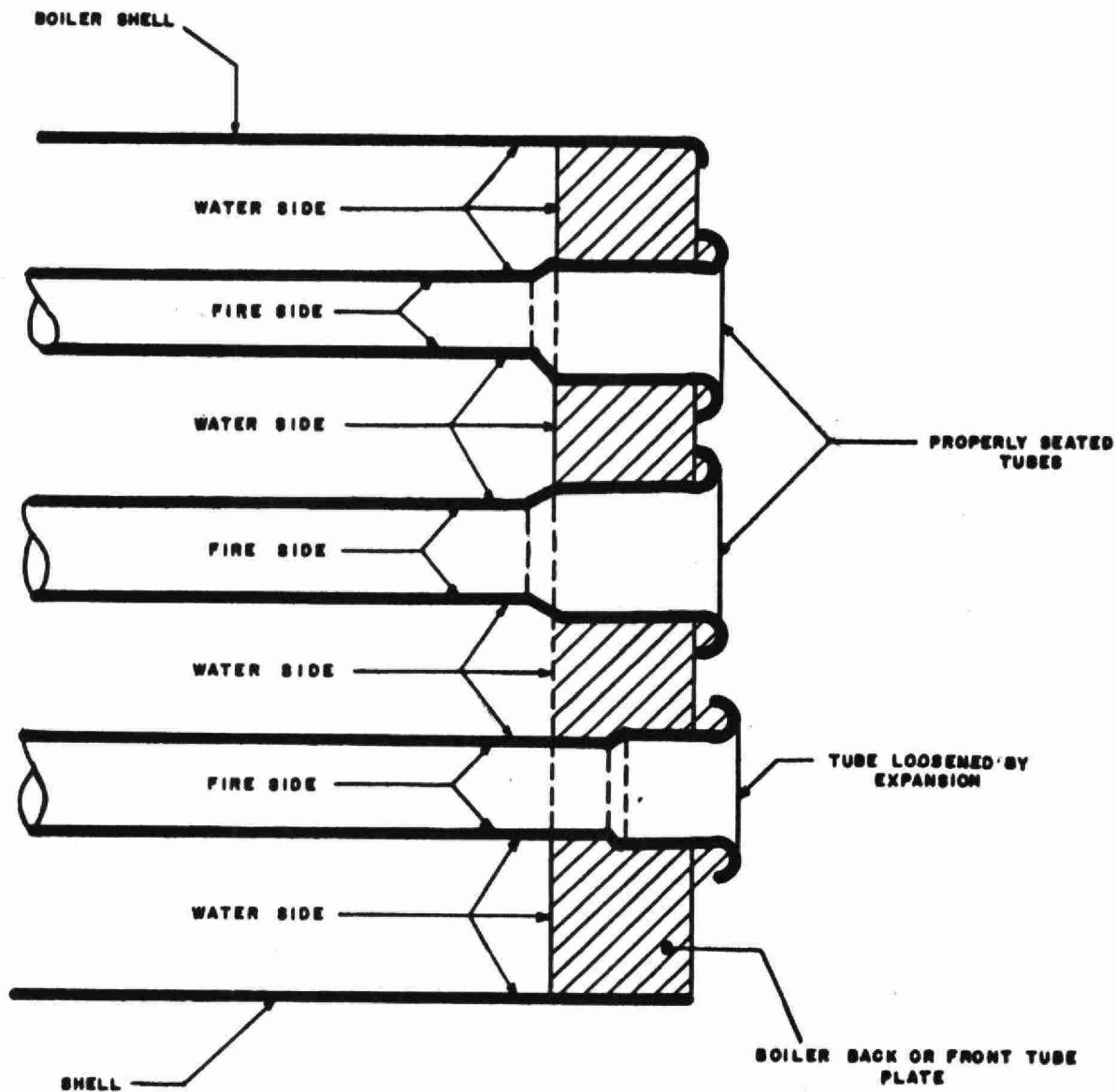
- A - SHUT OFF VALVE
- B - PRESSURE REDUCING VALVE  
 (THIS IS THE ACTUAL MAKE UP VALVE)
- C - SAFETY VALVE
- D - SHUT OFF VALVE
- E - BY-PASS VALVE

FIG. -2  
CUSHION TANK ARRANGEMENT



- A - CUSHION TANK
- B - SIGHT GLASS
- C - PET COCK FOR AIR ADMITTANCE DURING DRAINING
- D - GLASS DRAIN VALVE
- E - CUSHION TANK DRAIN VALVE
- F - PRESSURE GAUGE
- G - BOILER SAFETY VALVE

FIG. - 3



### STARTING UP

It is always good practice to start up a cold boiler very slowly. When metals are subjected to heat they expand. The same thing happens to the boiler metal but as long as this does not happen too fast there will not be any problem. However, if it does heat up at a fast rate the expansion will cause uneven stresses in the metals of the boiler and we are liable to loosen the tubes by expansion, this will cause the boiler to leak. (See Figure 3).

Start up your hot water circulating pumps before you start your burner. This will make sure that the whole system is warmed gradually. If we did not do this all the piping in the system would be filled with cold water and when the pumps are started with the boiler hot this cold water would cause a shock on the hot metal of the boiler and uneven stresses in the metal would be the result, which again in turn could cause tube leakage. Now we can start the burner. If you have a low fire arrangement on your boiler bring the temperature up on that setting. If you do not have this low fire arrangement on the boiler use intermittent fire, five minutes on and five minutes off until the operating temperature is reached.

### CONTROLS

We have a number of operating and safety controls on the boiler that are mandatory by law and should always be kept in good operating condition.

### LOW AND HIGH LIMIT CONTROLS

These controls are activated by a capillary sensing probe inside the boiler. This probe is a small metal bulb which is connected by a very thin tubing to a diaphragm inside (inside the control) which in turn is connected to a mercury switch. The bulb and the tubing are filled with either a fluid or a gas which expands when heated by the water. This expansion works on the diaphragm, which in turn activates the

mercury switch. This switch is hooked in series with the electrical circuit.

When the maximum operating temperature is reached the high limit switch will cut off the power and the burner stops. When the temperature has dropped sufficiently, the low limit control will activate the electrical circuit and the burner starts up again. The range between the low limit cut in and high limit cut out is about 10 degrees to 15 degrees Fahrenheit. It is wise to check the cut in and cut out points of these controls against the actual thermometer reading. (Approximately once a month).

Some boilers have a modulating control as well. Modulate means "to keep within proper range". This is exactly what a modulating control does. It keeps the boiler within the cut in and cut out range without the boiler cutting out all the time. When the temperature is approaching the maximum limit, the modulating control will cut the burner back to low fire, thereby preventing the boiler cutting out. This modulating feature is only found on the more elaborate models.

### SAFETY CONTROLS

We have a number of controls which are strictly for safety purposes and should be kept in good operating condition.

### FLAME FAILURE

Each boiler must have a flame failure device. This can be the flame rod type whereby the flame envelops a metal rod. The action of the flame sets up a mini current in this rod which is wired into the circuit and keeps the circuit closed. The moment the flame fails the mini current is broken and within 90 seconds the electrical circuit opens, shutting down the burner.



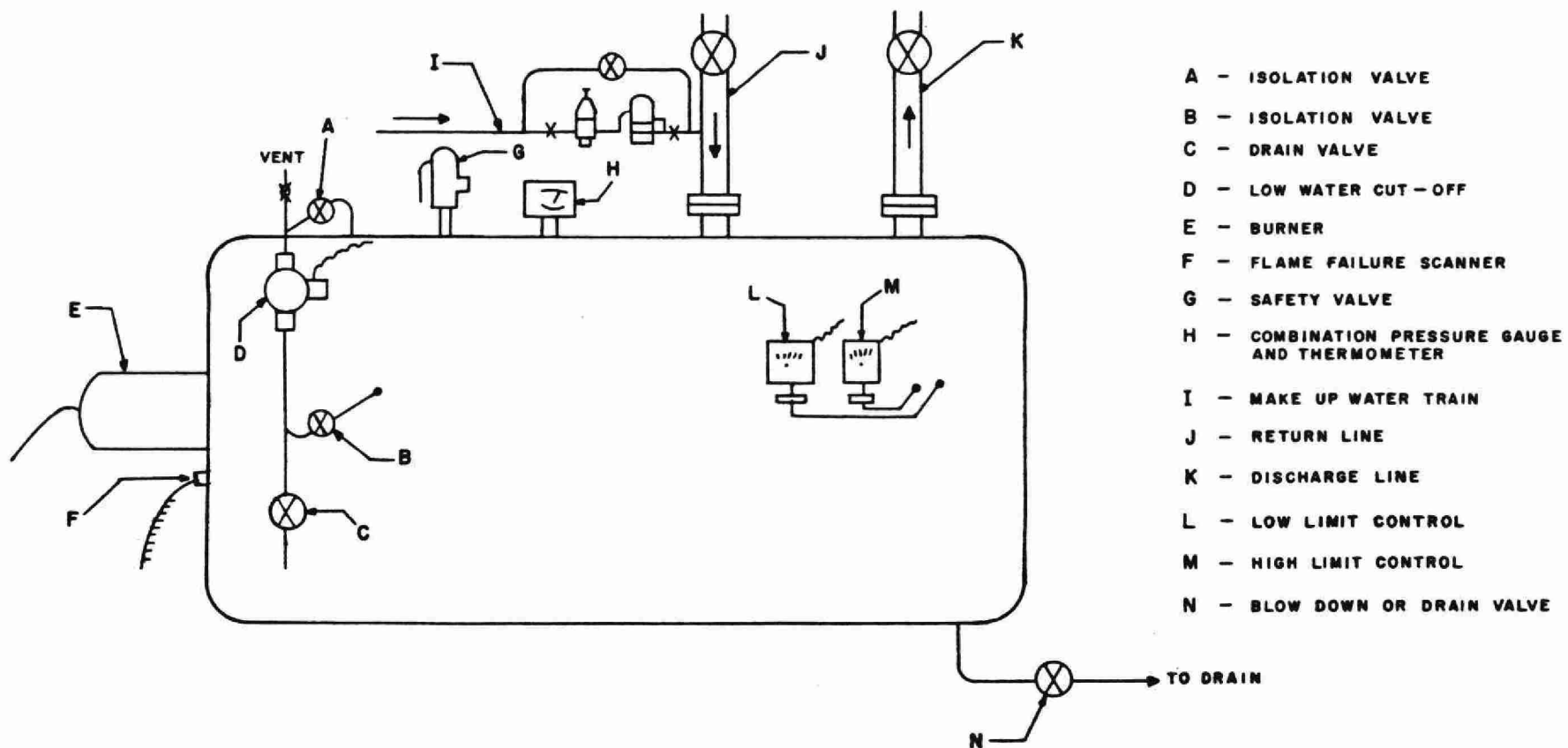
An ultra violet scanner is another type of flame failure device. This is an electronic eye which sees the ultra violet rays of the flame, again this causes a mini current to flow into the circuit, keeping the circuit closed and on flame failure shutting the burner down. Why is this device necessary? Let us assume that we have no protection and that for some unknown reason the flame fails. Oil or gas would pour into the combustion chamber and could be accidentally ignited, by a hot spark from the brickwork. This could cause an explosion which could cause extensive damage to the boiler. The flame failure device will prevent this by shutting down the burner before this can happen. It is good practice to check this device monthly by simulating flame failure. This is done by shutting off the fuel supply and check to see if the burner is shutting down within 90 seconds.

#### LOW WATER CUT OFF (Figure 4)

The low water cut off is another safety device. Usually this is a float operated switch which is wired into the circuit in series. When, for any reason, the water level in the boiler drops dangerously low the float drops, thereby opening the circuit and shutting down the burner.

For instance, if a tube should split during a period that the boiler was unattended (weekends) the level could drop dangerously low. If the boiler was still going an explosion could result, due to the weakening of the overheated boiler metal. Check the operation of the low water cut off monthly, many a switch has been found to be defective, it pays to be safe. Check this switch by closing off valves A and B in Figure 4 and opening drain valve C, with the burner in operation. The burner must shut down or something is amiss. If for any reason the water in the boiler has dropped below the top row of tubes never feed in cold water but shut the boiler down and let the boiler cool before feeding in the cold water. Cold water onto hot surfaces can set up dangerous stresses in a boiler by pulling loose or even splitting them. Always cool the boiler down and then start up as described earlier.

FIG.-4



### SAFETY VALVE

Each boiler must have a safety valve by law. This valve is found on top of the boiler and as close to the boiler as possible. (See Figure 4). It must be connected directly to the boiler without any valve between the safety valve and the boiler. If the outlet of the safety valve is piped down to a drain the piping must be supported in such a manner that no strain is exerted onto the valve body. The safety valve protects the boiler against any excessive pressure which might occur. Excessive pressure can occur in a number of ways. Someone could accidentally open the by-pass valve on the make up line, the pressure reducing valve on the make up line could stick open, or the high limit control could fail to operate and fail to shut the burner down.

In the latter case if it was not for the safety valve protecting the boiler the continuous heat would raise the pressure steadily to the point where the pressure would become too high and would rupture the boiler, if the safety valve did not protect the boiler. For hot water boilers safety valves are usually factory set to blow off at 30 psi. The safety valve however should be checked once a month by lifting the manual opening handle or by raising the boiler pressure by opening the by-pass valve on the make up line and checking if the valve will blow off at the pressure for which it is set. If it fails, replace it, do not try to repair it.

### BLOWDOWN OR DRAIN VALVE

Each boiler must also have a blowdown or drain valve. (See Figure 4). This valve is found at the lowest part of the boiler and should be the same size as the opening in the boiler provided for this purpose. It must not be reduced to a smaller size as so often is found. On hot water boilers this valve should not be opened except when water has to be drained out of the boiler.

### SHUTTING DOWN OF BOILER

This is done by pulling the boiler switch and letting the boiler cool down. Be sure to let the water circulating pumps run until the boiler is cooled down.

This boiler switch is usually located on the electrical panel and is an ordinary circuit breaker. With the boiler shut down, the time to do some preventive maintenance has arrived. The usual time for this is either in the spring or in the summer when the demand on the boiler is not so great.

One of the first jobs that you are probably all familiar with and loathe the most is that of punching tubes. What do we mean by punching tubes? It is the cleaning out of the fire tubes with a round wire brush or round scraper on a long rod, we commence pushing this brush back and forth through the tubes. It is a dirty job but a very necessary one. Soot is a very high insulator and when a layer of soot is found in the tubes the heat transfer through the tube walls into the water is greatly retarded. Actually this heat loss can be observed when the boiler is running. If you have a stack thermometer in your chimney you will notice that the temperature of the flue gases leaving the boiler are much higher in a dirty boiler than in a clean boiler. This additional heat loss causes higher fuel consumption because more fuel is required to obtain the same water temperature because of this heat loss.

The condition of your tubes gives you a good idea of your combustion efficiency. Combustion efficiency means the liberation of the largest amount of heat from the smallest amount of fuel used. It will be further explained in the "Intermediate" course. A poorly adjusted burner gives poor combustion and will make soot. When you see smoke coming out of your chimney you know your burner is out of adjustment and it is time to do something about it.

BRICKWORK

Brickwork in the combustion chamber should be checked during a shut down. Brickwork should always be in a good state of repair because it plays a vital role in the combustion process. When the boiler is running, this brickwork becomes hot. This heat is radiated back into the spraying zone of the fuel and the fuel becomes gaseous, thereby bringing it up to ignition temperature. If no brickwork was installed in the area of the flame, the oil particles would strike the cold metal surface. Instead of becoming gaseous the oil would form hard black carbon which eventually would fill up the combustion chamber and choke off the fire. If any breakdown of brickwork is noted, repair it immediately. Brickwork is also found in the back end of the boiler, this is more for insulation so that heat loss through the back end is kept to a minimum. This type of boiler is called a dry back boiler. Some boilers are water cooled on the back end and these are called wet back boilers.

BOILER PASSES

In some boilers the gases pass through the tubes only once before going up the chimney. This is known as a single-pass boiler. In other boilers gases may pass two or more times through banks of tubes before going up the chimney. These are known as multi-pass boilers. The passes are separated by brick baffles to prevent the gases from short circuiting through the tubes. It is important that these baffles are air tight. It stands to reason that if gases short circuit and only pass over part of the total heating surface a complete heat transfer cannot be obtained. Part of this heat will pass up the stack resulting in a higher fuel consumption. Rising stack temperatures are an indication of baffle breakdown. Repair them as soon as possible.

WATERSIDE OF THE BOILER

When the boiler is shut down it is also a good time to check the waterside of the boiler. This is too often neglected. Close the valves on the discharge and return line so that only the boiler is drained and not the whole system. Open the drain valve and open a valve on top of the boiler to break the vacuum created by the draining water. This can be done by blocking open the safety valve. When the boiler is drained remove the handhole covers or pipe-plugs provided for this purpose on the shell, and inspect the waterside. Look for scale pitting and corrosion.

Scale like soot, is a heavy insulator and retards the heat transfer through the metal. If scale formation is heavy enough it can actually cause the tube metal to be burned by the hot gases due to the lack of cooling. This will cause tube leakage. Pitting and corrosion shortens the life span of the boiler and results in expensive repair jobs. Treatment for this is widely used but will be dealt with in a later lecture.

External corrosion is another problem encountered in boilers. There is often a misconception about the internal and external side of the boiler. Let's clarify this; the internal side is always the side touched by water, while the external side is the side touched by flame or hot gases. Those of you who burn digester gas in the boiler have seen the rust deposits on the fire side of the tubes and back tube sheet, sometimes it is so bad that it hangs down in sheets from the tube walls. This is caused by the wetness of the digester gas and there is nothing we can do about it. We must faithfully drain our drip traps but this does not solve the problem. The only thing that will slow it down a little is to keep the stack temperature up to about 300° to 350° Fahrenheit, so that moisture can pass through as steam, but this is not always possible. This rust, of course, constitutes a loss of metal. It is therefore a good policy to check the tube thickness while the boiler is open. Do this at least once a year. This is done

by measuring the tubes that can be reached, both inside and outside diameters and divide the result by two. Some thicknesses for different tube sizes as set by A.S.M.E. Standards are as follows:

$$1 \frac{3}{4}" \text{ to } 2 \frac{1}{4}" = 0.095"$$

$$2 \frac{1}{2}" \text{ to } 3" = 0.109"$$

$$3 \frac{1}{4}" \text{ to } 3 \frac{3}{4}" = 0.120"$$

$$4" - - - - - = 0.134"$$

(I have here some samples from tubes that have actually failed and also some scale samples that actually show the shape of the tubes. If you wish you may examine them, and any questions you may have I will gladly try to answer them.)



## OPERATION AND MAINTENANCE OF SEWER SYSTEMS

R. E. Brown

Operations Engineer

### INTRODUCTION

I have recently estimated that to install a new sewer system to service a small municipality, would cost in excess of \$400.00 per capita or \$4,000,000.00 per 10,000 persons. Perhaps because these utilities are relatively out of sight, few municipalities practice the adequate operating and maintenance procedures warranted by their investment value and public health importance. Commonly, only when an emergency arises is any action precipitated and then usually only after a householder has had the shocking experience of having his basement flooded from the sewers. If he knew that this might have been avoided by adequate municipal operations, he would be even more shocked.

It is important, therefore, that steps be taken for the prevention of the inconveniences and damages, together with the efficient operation of this utility that represents such a large investment to the municipality.

### SEWER CLEANING METHODS

A sewer system consists of sewers, manholes, pumping stations and other appurtenances. A sewer's capacity to carry water-borne wastes is dependant primarily on its cross sectional area and the slope on which it has been laid. It is hoped that the sewer was designed and installed at a grade to produce a minimum flow velocity of two feet per second to prevent sedimentation, however, sedimentation often does occur and where sediment, rocks, rags, lumber, roots, grease or other waste products reduce the cross sectional area, the sewer department should embark on an active maintenance program.

In the small municipalities the works superintendent is commonly expected to be a jack-of-all-trades and, depending upon the attitude of council, he may be allowed an assistant to do some of the heavy work. Here, sewer cleaning is commonly performed on a "wait for a complaint" policy and is usually accomplished by means of wooden rods

manipulated from within the manholes.

With the increasing size and awareness of the municipality, a crew of men is often established for both water main and sewer work and hydraulically propelled sewer cleaning devices appear. A rotating nozzle, cutter or "ferret" attached to a fire hose, an inflated rubber ball, various hydraulic scrapers, a flush bag, sewer hoe, sand cup, and sewer scooter, all have been and are still used, but are considered by some authorities to be obsolete.

During this phase of development, flexible steel rods may also appear with various root cutter, sand auger, corkscrew attachments, together with power take-offs which impart a rotating action for improving this rodding and cleaning of the sewers.

Eventually, the municipality's size and/or enlightenment, results in the purchase of bucket machines. Here, winches at adjacent manholes pull a bucket-like attachment through the sewer to allow surface disposal of the extraneous material.

It is necessary to rod the sewers to place the winch cable between manholes. As the number of bucket machines in a municipality increases, regular rodding machines become inefficient. To overcome this limitation, and to provide a means for rapid clearing of emergency blockages, separate rodding machines capable of placing rods at a rate of up to 100 feet per minute are ultimately acquired.

These phases have been presented to indicate that the basic sewer cleaning equipment and associated staff are usually dependant upon the size and/or the enlightenment of the municipality.

#### OPERATION AND MAINTENANCE RECORDS

It is important that each municipality realize the necessity of adequate operation and maintenance procedures and records. The "wait for a complaint" attitude is to be avoided and preventative maintenance is to be desired.

Inspections, therefore, are an integral part of any program. When trouble areas are discovered, inspections and cleanings should be scheduled on a more frequent basis

than that used for the rest of the sewer system.

An accurate record of the location and depth of the sewers, manhole covers and other appurtenances is essential. Complete as-built maps and plans should be available for all portions of the sewer system including the location of all wyes installed for future connections. These plans should also show all other utilities and buried cables known to be in the area, and should be kept up to date. Area maps are useful to indicate the related sewer areas and systems. An overall map can be used to indicate the frequency and completeness of the cleaning program.

In addition, it is desirable to maintain written records on the conditions found at the time of inspection, the work performed, the time taken, any special problems encountered and the date. Some examples of forms used in two different municipalities are appended to this paper.

#### NEW EXTENSIONS

When extensions are made to the system, care must be exercised to avoid allowing silt or sand or other construction debris to enter the original system, which would upset the cleaning program. This may be accomplished best by temporarily sealing the sewer at the junction manhole. Building connections improperly installed in new and established districts can also contribute extraneous material to the system. All unused lateral connections should be properly sealed. It is a temptation to builders and drain layers to dispose of all silt laden excavation water to the sewer, therefore, this activity should be controlled. Care should also be taken to ensure that building downspouts are not allowed to contribute to separate sanitary sewers. To these ends, building connection permits should be required to ensure a proper installation and to provide a record of the connection's location. A plumbing permit should similarly also be required.

#### MATERIALS IN SEWER CONSTRUCTION

In both sewer and building connection construction, the most efficient materials should be used to minimize future problems. New tight, flexible joints are allowing appreciable progress towards limiting infiltration and root penetration of sewers and connections. With the increased cost to municipalities for sewage treatment, every effort

should be made to minimize the amount of infiltration flows requiring treatment. There is little advantage in specific treatment plant design if sewer laying and jointing is to be a haphazard process. Many treatment plants have been prematurely hydraulically overloaded in recent years due to abuse in the construction and use of an otherwise good sewer system.

#### CELLAR FLOODING COMPLAINTS

Of interest to all municipalities is the proper processing of cellar flooding complaints. It is usually considered that the municipalities' legal responsibility in regard to building connection operation, terminates at the private property line. Sometimes, however, the location of a blockage is in doubt. To avoid later litigation, it is common to insist that no claim for damages will be entertained unless the sewer department is called to investigate before any action is taken by a plumber, in order to ascertain if the blockage occurred on municipal or private property. A small service charge could be made for this work. A crew should be dispatched promptly to aid the homeowner even to the extent of assisting in cleaning and removing articles which may have been damaged or will be damaged if left in place. Bylaws may be enacted to deny acceptance of responsibility, by performing such assistance by the municipality. A clean-out on the building connection at the property line with a riser to the surface would allow rapid evaluation of the location of the blockage. If the connection was dry there, the blockage would be on the private portion. If it were found to be filled with liquid, the blockage would be on the municipal portion. Also, the clean-out would then allow the entrance of sewer rods at this point to clear the blockage. Alternately a clean-out just inside the residence should always be required.

#### ROOT BLOCKAGES

In treed areas, roots are often the worst cause of blockages. In clay soil, deep root penetration usually is not encountered; however, in sandy soil during the summer season, the tree roots will extend to the sewers when they exert severe pressure to enter the joints. Therefore, root-proof connections are necessary and in these known trouble areas, programs are common, to replace original materials with more root-proof and water-tight types.

### BUCKET MACHINES

I have suggested that the acquisition of equipment and proper programming is relative to the size and enlightenment of the municipality. Probably, the most significant step forward that the growing municipality will take in sewer cleaning will be the acquisition of the bucket machine. Prior to this time, manual labour, together with the assistance of hydraulic aids, will have been the rule. With these methods, that rely on the flush action of a flow of water, an attempt is made to capture the disturbed material at the downstream manhole, however, a large amount of material usually escapes to settle further downstream in the system. Flushing operations also produce an extra hydraulic load on the treatment plant, together with sudden increased grit and suspended solids quantities, odours and biochemical oxygen demand. If these methods are used, some attempt should be made to determine the seriousness of the treatment plant overload.

These methods really offer only partial relief and the cleaning program is not really effective until the material is physically removed from its initial position in the sewer for surface disposal, by units such as the bucket machines.

When a rodding machine is used in connection with several bucket machines, temporary cables or wires are sometimes rodded into the sewers in advance of the machines to be used shortly to speed up this work. Sometimes these bucket sewer cleaning operations are concentrated during winter months when permanent staff is more readily available.

### SEWER ORDINANCES

If sewer maintenance and sewage treatment is to be effective, sewer ordinances are necessary. The discharge of harmful industrial or commercial wastes should be controlled and where excessive sewer cleaning will be required, it should be reflected in the individual connection cost or service rate. Inspection holes or manholes on these connections will allow inspection of the effluent from these problem sources. Industrial waste and sewer use bylaws are becoming common in municipalities that have experienced problems threatening their system and also in many municipalities where new systems are being installed.



### MANHOLE COVERS

In many areas, some roads are resurfaced each year with a resulting slight rise in road level. Manhole tops are often buried. Tar and gravel, when used is often indiscriminantly poured on manhole covers and will often seal them into place and plug the vent holes. A program should be continued to raise these manholes where necessary, to allow easy location, to prevent the entry of run-off water and stones, and to allow proper ventilation of the manhole. The road maintenance crews should be asked to co-operate fully with the sewer maintenance crews whenever a change in grade is anticipated.

### PUMPING STATIONS

Pumping stations form an integral part of a sewer system and must be properly maintained in order to ensure that the sewer system does its job effectively. In many systems a pumping station if inoperative, will cause serious surcharging of the sewers and may result in flooded basements. Home owners have been known to sue for and win claims of several hundred dollars due to a pumping station failure.

In smaller municipalities, pumping station maintenance is often the responsibility of the same crew that inspects and cleans the sewers as well as operating the treatment plant. In others, the jobs may be separated.

Pumping station failures are usually the result of a mechanical or electrical failure or commonly due to objects within the sewage. Electrical and mechanical problems will not be discussed here as they will be covered in other lectures.

Many failures are due to the impeller becoming clogged with rags, small sticks, or other fibrous materials. Although the pump will run, very little sewage is pumped. Other failures occur when check valves are held open by sticks allowing internal re-circulation in dual pumping stations. Occasionally a 2 x 4 piece of lumber will stop a pump from rotating. Screens, shredding machines and other patented devices depending on reversible flow can reduce the frequency of pump problems, but introduce new problems of their own and should be avoided unless serious operating problems result. Many types of non-clogging pumps are available and should be used in preference to other devices.

It has been our experience that daily inspections of pumping stations are desirable and for some critical stations, especially those without emergency overflows, inspection 2 or 3 time a day may be found necessary. High water alarm systems are often used in these stations.

Some pumping stations have wet wells designed such that sedimentation of grit and organic materials becomes a problem under low flow conditions. Periodic cleaning and flushing is desirable to prevent odours as this material becomes septic.

As with any other part of the sewer system, records must be kept on a daily basis of the condition of the pumping station, and a regularly scheduled maintenance program is desirable. Emergencies as a result of negligence in maintenance, can become very expensive.

#### GENERAL

With the advent of newer industrial wastes, and the greater danger of gasoline spillages and leakages, facilities should be provided for regular testing for explosive gases, in the sewer system.

The installation of radio communication units in some of the vehicles in a larger municipality will improve the efficiency of the program, particularly in providing more rapid response to emergency blockage complaints.

Some municipalities prefer closed, one-ton utilities trucks with locked compartments. All such units should be well marked with flashing lights and adequate traffic markings. Warning signs and barriers should be erected around any opened manhole.

As the municipality grows, portable air compressors, generators, air blowers and other specialized equipment will all be acquired. Proper yard facilities are always required. Cleanliness must always be borne in mind due to the nature of the work. Safety could be the subject of a complete lecture and it is not proposed here. However, due to the possible occurrence of toxic gases and the more deadly complete



absence of oxygen, it is recommended that safety harnesses be used whenever any manhole is entered with a minimum of two men standing by at the surface.

In recent years, the innovation of sewer inspection by camera boat and closed circuit television apparatus has become quite common for larger municipalities. Many firms have gone into the business of providing this service so that a municipality does not have to purchase the equipment to enjoy the benefits.

#### SUMMARY

Regardless of the size of the municipality, a large per capita investment is represented in its sewer system. In order to protect this investment, confirm its public health purpose and avoid unnecessary inconvenience, it requires adequately manned programs of operation and maintenance. Average costs indicate that regular maintenance in the long run is no more expensive than furnishing emergency maintenance only.

## POINT EDWARD

## SEWER INSPECTION SHEETS

INSPECTED BY ..... DATE .....19.....

STREET .....M.H. #.....TO M.H. #.....ROUTINE ☐  
EMERGENCY ☐CONDITION OF MANHOLE # .....MANHOLE COVER:

PROPERLY SEATED? .....YES....NO....

AT PROPER ELEVATION? .....YES....NO....

MANHOLE STEPS:

REQUIRED NO. PRESENT? .....YES....NO....

STRUCTURALLY SOUND? .....YES....NO....

IF A DROP MANHOLE WAS STOPPER  
REPLACED?.....YES....NO....IS MANHOLE CYLINDER STRUCTURALLY  
SOUND?.....YES....NO....REMARKS.....  
.....  
.....CONDITION OF SEWERIS THERE EVIDENCE OF SAND INFILTRATION THROUGH  
JOINTS .....YES....NO....

IS THERE CONSIDERABLE SEDIMENTATION IN SEWER YES....NO....

DEPTH OF FLOW .....INCHES.....  
TIME .....REMARKS.....  
.....  
.....CHECK IF WORK REQUIRED ☐

INSPECTED BY ..... DATE .....19.....

STREET .....M.H. #.....TO M.H. #.....ROUTINE ☐  
EMERGENCY ☐CONDITION OF MANHOLE # .....MANHOLE COVER:

PROPERLY SEATED?.....YES....NO....

AT PROPER ELEVATION?.....YES....NO....

MANHOLE STEPS:

REQUIRED NO. PRESENT?.....YES....NO....

STRUCTURALLY SOUND?.....YES....NO....

IF A DROP MANHOLE WAS STOPPER  
REPLACED?.....YES....NO....IS MANHOLE CYLINDER STRUCTURALLY  
SOUND?.....YES....NO....REMARKS.....  
.....  
.....CONDITION OF SEWERIS THERE EVIDENCE OF SAND INFILTRATION THROUGH  
JOINTS .....YES....NO....

IS THERE CONSIDERABLE SEDIMENTATION IN SEWER.....YES....NO....

DEPTH OF FLOW .....INCHES.....  
TIME .....REMARKS.....  
.....  
.....CHECK IF WORK REQUIRED ☐

# MAINTENANCE RECORD CARD

[illegible]

Slope of Sewer ..... (ft. per 100 ft.)

SEWER MAINTENANCE ORDER

ISSUED BY: ..... ISSUED TO: ..... DATE ..... TIME .....  
SECTION OF ..... MAIN TO BE CLEANED: .....  
STREET ..... FROM M.H. .... TO M.H. ....  
SEWAGE DRAINAGE AREA PLAN NO. .... PROFILE DRAWING NO. ....  
CREW PERSONNEL: .....  
WORK STARTED: DATE ..... TIME ..... WORK COMPLETED: DATE ..... TIME .....  
IF WORK DELAYED, STATE REASON .....

1. CONDITION OF OUTLET M.H.

MANHOLE COVER:  
PROPERLY SEATED? .....YES.....NO....  
HOLES OPEN? .....YES.....NO....  
AT PROPER ELEVATION? .....YES.....NO....  
DO CONNECTIONS COME TO M.H.? .....YES.....NO....  
IF A DROP M.H., WAS STOPPER  
REPLACED? .....YES.....NO....  
MANHOLE STEPS:  
REQUIRED NUMBER PRESENT? .....YES.....NO....  
STRUCTURALLY SOUND? .....YES.....NO....  
IS BENCHING PROPER? .....YES.....NO....  
REMARKS:

2. CONDITION OF INLET M.H.

MANHOLE COVER:  
PROPERLY SEATED? .....YES.....NO....  
HOLES OPEN? .....YES.....NO....  
AT PROPER ELEVATION? .....YES.....NO....  
DO CONNECTIONS COME TO M.H.? .....YES.....NO....  
IF A DROP M.H., WAS STOPPER  
REPLACED? .....YES.....NO....  
MANHOLE STEPS:  
REQUIRED NUMBER PRESENT? .....YES.....NO....  
STRUCTURALLY SOUND? .....YES.....NO....  
IS BENCHING PROPER? .....YES.....NO....  
REMARKS:

3. GENERAL CONDITION OF SEWER AS SEEN FROM OUTLET  
MANHOLE .....  
.....  
.....  
DEPTH OF FLOW .....INCHES ..... TIME .....

4. GENERAL CONDITION OF SEWER AS SEEN FROM INLET  
MANHOLE .....  
.....  
.....  
DEPTH OF FLOW .....INCHES ..... TIME .....

5. WAS THERE ANY ABNORMAL DIFFICULTY GETTING  
BUCKETS THROUGH PIPE? .....YES.....NO....  
IF SO, WHERE? .....  
.....  
WAS THERE ANY DIFFICULTY IN GETTING BUCKETS  
THROUGH M.H.? .....YES.....NO....

6. DO YOU SUSPECT A COLLAPSED OR BROKEN  
PIPE? .....YES.....NO....  
IF SO, WHAT IS THE LOCATION? .....  
.....  
NO. OF WORK ORDER ISSUED.....

7. DOES THERE APPEAR TO BE ANY INFILTRATION OF SAND  
INTO THE SEWER IN THIS SECTION DUE TO POOR  
JOINTS? .....  
IF SO, WHERE? .....  
NO. OF WORK ORDER ISSUED.....

8. WAS ANY OTHER OBSTRUCTION FOUND? YES.....NO....  
IF SO, WHAT? .....  
IF SO, WHERE? .....  
NO. OF WORK ORDER ISSUED.....

WHAT TYPE OF MATERIAL WAS REMOVED FROM THE SEWER? .....  
WHAT QUANTITY OF MATERIAL WAS REMOVED? .....  
GENERAL REMARKS .....  
.....

M.H.  
O

M.H.

## OPERATION OF AUXILLIARY STAND-BY

### POWER EQUIPMENT

#### FUNDAMENTAL PRINCIPLES - DIESEL AND GASOLINE ENGINES

P. T. Singh  
Technical Specialist

The following deals with the basic principles which are applicable to all engines. However, engines of different types and makes differ greatly in details. Therefore, for specific instructions regarding a particular make of engine one should always refer to the engine builder's manual.

Both diesel and gasoline engines are internal combustion engines. An internal combustion engine is classified as a heat engine whereby its power is produced by burning fuel. The power stored in the fuel is released when it is burned. The word internal means that the fuel is burned inside the engine itself. The most common fuel used are diesel oil for diesel engines and gasoline for gasoline engines. An ample supply of oxygen is required for proper combustion.

#### BASIC ENGINE PARTS

The most essential of these parts that make up both diesel and gasoline engines are: the cylinder, cylinder head, piston rings, connecting rod, crankshaft, flywheel, valves, camshaft and crankcase.

##### Cylinder

The cylinder is made of cast-iron. It is round and has a finely machined surface in which the piston slides up and down.

##### Cylinder Head

The cylinder head is made of cast-iron, and is bolted tightly to the top of the cylinder. It also forms the top of the combustion chamber. It contains the fuel injector for a diesel engine and a spark plug for the gasoline engine.

### Piston

The piston, commonly made of aluminum, slides up and down in the cylinder. The duties of the piston are to compress the air charge and to receive the pressure of the burning and expanding gasses.

### Piston Rings

The piston rings provide a tight seal between the piston and the cylinder wall. Without the piston rings the expanding gasses would escape into the crankcase. The piston rings also reduces friction and control lubrication of the cylinder wall.

### Connecting Rod

The connecting rod, made of steel, connects the piston and the crankshaft. It is the duty of the connecting rod to transmit force in either direction between the piston and the crank on the crankshaft.

### Crankshaft

The crankshaft, made of steel, converts the reciprocating motion of the piston into rotary motion.

### Flywheel

This is a very heavy wheel made of cast iron. It is fastened firmly to the crankshaft and its purpose is to smooth out the operation of the engine. When the force of combustion pushes the piston down, the momentum of the flywheel helps to move the piston back up the cylinder. This eliminates the intermittent jolts of power during combustion.

### Valves

The valves are used to admit air and discharge the exhaust gasses from the cylinder.

### Camshaft

The camshaft is driven by the crankshaft and controls the opening and closing of the inlet and exhaust valves. On diesel engines it operates the fuel pump.

### Crankcase

The crankcase made of cast iron, houses the crankshaft and has bearing surfaces on which the crankshaft revolves.

The lubricating oil pump and reservoir of oil are located in the crankcase.

### CYCLES OF OPERATION

Diesel and gasoline engines operate on either the two-stroke or four-stroke cycle of events in each cylinder. This means that it requires either two strokes or four strokes of the piston to:

1. draw in a charge of air
2. compress it to a high pressure and temperature
3. burn the fuel and allow the gasses to expand
4. deliver their power to the crankshaft and blow out the exhaust gasses so that the cylinder is ready for the next cycle.

One revolution of the crankshaft completes a cycle in a two-stroke cycle engine. Two revolutions of the crankshaft completes a cycle in a four-stroke cycle engine.

The most common method of engine operation is the four-stroke cycle. It is an efficient and successful producer of power. Its operation is explained in detail below:



## HOW DIESEL AND GASOLINE ENGINES WORK

The main difference between a diesel and a gasoline engine lies in the "ignition system". In a diesel engine the high temperature of the compressed air produces the ignition. In a gasoline engine, a spark produced by a magneto or battery-coil ignites the fuel.

### OPERATION OF THE FOUR-STROKE CYCLE

#### 1. Suction

In the gasoline engine, fuel and air mixture are drawn into the cylinder during the first or induction (suction) stroke. In the diesel engine, however, only filtered air is drawn into the cylinder.

#### 2. Compression

During the second stroke of the gasoline engine, the fuel and air mixture is compressed to a suitable pressure prior to ignition.

In the case of diesel, the air is compressed to a much higher degree and, therefore, becomes extremely hot.

#### 3. Expansion

During the third stroke of the gasoline engine, the compressed fuel and air mixture has been ignited by an electrical spark from the spark plug.

In the diesel engine, raw fuel is injected at high pressure in the form of an atomized spray into the already hot compressed air in the engine cylinder. This causes the fuel to ignite and the resultant expansion in the cylinder gives us the power stroke.

#### 4. Exhaust

During the fourth and last stroke of both gasoline and diesel engines, the burnt gases are expelled from the cylinder prior to the next stroke and new cycle.

## OPERATING POINTERS

For efficient operation, both diesel and gasoline engines require:

1. Air - An abundant supply of air for proper combustion which must be filtered to prevent internal engine surface from being damaged by abrasive material the air might carry.
2. Fuel - Good quality, clean fuel with the best filtering system between supply tank and engine. A constant supply must be maintained.
3. Lubrication - High grade quality of lubricating oil and a reliable pump driven off the engine to deliver oil continuously at pressures ranging from 30 to 75 p.s.i.g. (depending on manufacturer recommendation) to hundreds of moving parts.

A filtering system to remove sludge and dirt.

4. Cooling - An efficient cooling system to maintain a working temperature of no less than 165° F and not higher than 180° F on jacket water and not over 150° F on lubricating oil.
5. Speed Control - To maintain a definite speed or a specific speed range without speed fluctuations a governor is required to control fuel in accordance with engine load.
6. Ignition Systems -  
Gasoline Engine - The purpose of the ignition system is to supply the high voltage sparks to the engine to ignite the compressed air-fuel charges as the piston approaches top dead centre on the compression stroke. The ignition system consists of an electric storage battery, a switch, an ignition distributor, ignition coil, spark plugs and wire. Some engines have an agnetoes to provide the spark for ignition.

Carburetor - The carburetor has the job of mixing air and fuel in the proper proportions to form a combustible mixture. The proportion of air and gasoline must be correct for good engine operation.

Diesel Engine - In a diesel engine, the fuel pump meters and forces fuel under very high pressure into the injector where it is discharged in an atomized form into the cylinder.

The heat of the compressed air in the cylinder ignites the fuel.

7. Starting System - Both types of engines are provided with D.C. starting motors to crank them. The starting battery is the most important part of the system and should never be ignored. It should always be kept fully charged.

Many plants are equipped with very efficient two rate battery chargers which should be used in order to keep the battery fully charged without damage from overcharge. Keep battery filled with distilled water and test frequently.

#### TEST STARTING AND RUNNING ENGINES

Every auxilliary stand-by unit should be test started and run for a period of two hours at least once a week. This running period in addition to bringing engine to running temperature will eliminate rapid carbonization, drive out condensation and maintain a film of lubrication - so necessary on all bearing surface.

#### PERFORMANCE RECORDS

Complete records of engine performance should be kept. Whenever the engine operates, record the following:

Cooling water temperature, Lube oil pressure and temperature, Exhaust temperature, if equipped, Electrical or other load data, RPM and total running hours.

It is in these records that the watchful operator spots small troubles when they can be cured inexpensively. A comparatively minor engine trouble, if not recognized and remedied in its early stages, may easily develop into a major breakdown.

BASIC HYDRAULICS

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INTRODUCTION

Hydraulics is the science of fluid flow. The science deals with the flow of fluids in pipes, channels, pumps, etc. In this paper, we will be considering the fluid of water, with solids being in suspension, in forcemains and sanitary sewers, etc.

In this paper, we will consider some basic hydraulic principles and briefly discuss some applications of these principles.

UNITS

The use of correct units in hydraulics is essential. The formulae used in hydraulics are not complicated but demand that correct units be used or otherwise incorrect solutions will result. If a particular unit is not in the form desired, then we must be able to convert to the desired unit.

The definitions given below are required in the following part of the paper. See Table 1 for a list of symbols and short forms used in hydraulics.

(a) Discharge

Discharge,  $Q$ , is the volume of water passing a given point in a specific time. Operators are all familiar with the unit gallons per minute (GPM), million gallons per day (MGD), and are perhaps less familiar with cubic feet per second (CFS). The operator must be able to convert from cfs to GPM to MGD with ease. To do this, the following rules apply:

$$1 \text{ MGD} = 694 \text{ GPM}$$

$$1 \text{ MGD} = 1.86 \text{ cfs}$$

$$1 \text{ MGD (US)} = 1.55 \text{ cfs}$$

$$1 \text{ cfs} = 373 \text{ GPM}$$

(b) Pressure

Pressure, P, may be defined as force per unit area. Pressure may be expressed in terms of pounds per square inch (psi), pounds per square foot (psf), and feet of water (ft.). Inches of mercury can also be used but this is not common unless dealing with special gauges which do not concern the operator in this course. The following rules apply to pressure:

$$1 \text{ psi} = 144 \text{ psf}$$

$$1 \text{ psi} = 2.31 \text{ ft. of water}$$

$$1 \text{ psf} = 0.016 \text{ ft. of water}$$

$$1 \text{ ft. of water} = 0.433 \text{ psi}$$

(c) Velocity

Velocity, V, may be defined as length per unit time. When referring to the speed of a car moving 30 miles per hour, the reference is to the velocity of the car. In hydraulics, water velocity is expressed almost exclusively in feet per second (fps).

(d) Slope

Slope, S, may be defined as height of rise or depth of fall per length of run. This term is used when referring to the slope of a sewer or the slope of the energy gradient in either open channels or sanitary forcemains. The units commonly used in referring to slope are feet per foot, feet per 100 feet, feet per 1000 feet, or feet per mile. The common use in hydraulics is the fall in feet per foot of a sewer expressed as per cent. If a sewer has a slope of 0.3% this would mean that the sewer has 0.3 feet fall in a length of 100 feet.

(e) Weight-Volume Relationships

When referring to sewage for the purposes of hydraulics calculations the volume and weight is assumed to be equal to that of the weight and volume of an equivalent amount of pure water. This may be taken as being very close to the truth since the major part of sewage is water with either organic solids or grit entrained in solution or in suspension. The grit would be heavier than water and the organic solids may be either heavier or lighter than water. The approximation for simplicity sake is then used. The

fact that the water contains some solids and grit are taken into account in other ways when considering friction losses. The following conversions apply:

1 cubic foot of water weighs 62.4 lbs.

1 gallon of water weighs 10 lbs.

1 US gallon of water weighs 8.33 lbs.

(f) Volume-Volume Relationships

The following conversions apply:

1 Imperial gallon = 1.2 US gallons

1 cubic foot of water = 6.24 gallons

PRINCIPLE OF CONTINUITY

This axiom is the most fundamental principle in hydraulics. Referring to Figure 1 at the back of the notes, the discharge "Q" is the same in Section 1 as in Section 2 of the pipe or sewer. The velocity at Section 1 is  $V_1$  and the cross-sectional area is  $A_1$ . The velocity at Section 2 is  $V_2$  and the area is  $A_2$ .

A is expressed in square feet

V is expressed in feet per second

Q is expressed in cubic feet per second

We may therefore write the equation:

$$Q = A_1 V_1 = A_2 V_2 \quad \text{Equation 1}$$

From equation 1 and using simple mathematics, the following expressions may be determined:

$$V_1 = \frac{Q}{A_1} = \frac{A_2 V_2}{A_1}$$

$$V_2 = \frac{Q}{A_2} = \frac{A_1 V_1}{A_2}$$

Example:

Given:  $A_1 = 1.396$  sq. ft. (16" diameter pipe)

$A_2 = 3.142$  sq. ft. (24" diameter pipe)

Required: Find the velocity at Section 1 and Section 2 if the discharge "Q" is 2340 gallons per minute

Solution:  $Q = 2340$  gallons per minute

$$= \frac{2340}{37.3} = 6.28 \text{ cu. ft. per second}$$

$$V_1 = \frac{Q}{A_1} = \frac{6.28}{1.396} = 4.5 \text{ ft. per second}$$

$$V_2 = \frac{Q}{A_2} = \frac{6.28}{3.14} = 2 \text{ ft. per second}$$

BERNOULLI PRINCIPLE

This theory is presented only to show the operator how various forms of energy exist in a hydraulic system. The operator is not expected to perform complicated calculations using formulae.

Bernoulli's principle deals with energy and says that the total energy in a system is always the same. However, the energy is in different forms at different locations in the system.

The energy may be in the form of:

1. pressure energy
2. potential energy
3. kinetic energy
4. heat energy

Energy is expressed in foot-pounds per pound. The pound term cancels out and we refer to energy in terms of feet of water or head.



### Pressure Energy

Pressure energy or pressure head has been defined in terms of psi, psf, and feet of water. When referring to pressure energy we will use the unit of feet of water. In a pressure system such as a forcemain connected with a sewage pumping station the line connecting the top of the pressure energles along the forcemain is called the hydraulic gradient. This is the line to which the water would rise if plezometers were placed on the pipeline and the water was allowed to seek its own level. In open channel flow the pressure energy is simply the hydrostatic head since the surface of the water is at atmospheric pressure. Such a flow occurs in sewers and channels in a sewage treatment plant. Sewers are not usually flowing full and the hydraulic gradient is simply the water level in the sewers.

### Kinetic Energy

Kinetic energy is the energy due to velocity and is defined as  $V^2/2g$  where  $g$  is "the acceleration due to gravity".

$$g = 32.16 \text{ feet per second per second}$$

Kinetic energy is also defined in units of feet.

#### Example:

Given: The cross-sectional area  $A$  of a pipe  
= 1.396 sq. ft. (16" diameter pipe)

Required: What is the kinetic energy of the pipe  
if the discharge in the pipe is 4680  
gallons per minute

Solution:  $Q = 4680 \text{ GPM}$

$$= \frac{4680}{37.3} = 12.56 \text{ cfs}$$

$$V = \frac{Q}{A} = \frac{12.56}{1.396} = 9 \text{ fps}$$

$$V^2/2g = \frac{9^2}{2g} = \frac{81}{64.4} = 1.26 \text{ ft.}$$

The kinetic energy is therefore 1.26 ft.

As can be seen from the above example, the kinetic energy is not usually significant when in comparison to the pressure energy which may be as high as 100 feet in a forcemain.

### Potential Energy

Potential energy is the energy of water due to its elevation (height) above a datum plane or reference point.

The unit for potential energy is also feet since we are measuring only vertical distance.

### Heat Energy

Heat energy or head loss occurs whenever water flows in a system, whether it be a pressure system or a gravity system. Head loss is due to the water particles rubbing on each other and on the pipe or channel walls and obstructions in the flow path.

This energy is lost from the system and can never be regained, since the heat is dissipated through the pipe walls. Thus we call it head loss because the only useful energy in a system is either velocity head, pressure head or potential head. Heat energy is created but velocity head, pressure head or potential head is lost. The unit to express head loss is feet.

Head loss may be classified into the following categories:

1. Major head losses
2. Minor head losses

Head losses increase in direct proportion to the velocity head in a conduit.

Head loss,  $H_L$ , is directly proportional to  $v^2/2g$ .

$$\text{Since } Q = AV, \quad V = \frac{Q}{A}$$

$$\text{Therefore, } v^2/2g = \left( \frac{Q}{A} \right)^2 \times \frac{1}{2g}$$

therefore,  $H_L$ , is directly proportional to

$$\left( \frac{Q}{A} \right)^2 \times \frac{1}{2g}$$

For a given area of conduit the head loss will vary directly as the flow, or conversely, for a given flow the head loss will vary inversely as the area.

Example:

Given: The head loss in a 12 forcemaln is 5 feet when the flow is 3.5 cfs (1.88 MGD)

Required: What is the head loss at 7.0 cu. ft./sec.

$$\text{Solution: } V = \frac{Q}{A} = \frac{3.5}{0.785} = 4.47 \text{ fps}$$

$$\text{Therefore, } V^2/2g = \frac{(4.47)^2}{2.0 \times 32.2} = 0.31 \text{ ft. at}$$

$$Q = 3.5 \text{ cfs}$$

$$\text{when, } Q = 7.0 \text{ cfs}$$

$$V = \frac{7.0}{0.785} = 8.94 \text{ fps}$$

$$V^2/2g = \frac{(8.94)^2}{2 \times 32.2} = 1.23 \text{ ft.}$$

$$\text{thus, the head loss at 7.0 cfs is } \frac{1.23}{0.31} \times 5 = 20 \text{ ft.}$$

This example illustrates that by doubling the flow the head loss is quadrupled.

Major Losses

The losses which we refer to as major losses occur in straight lengths of conduit. These losses are called major because in a real system most losses occur due to the long lengths of conduit through which the water or sewage must pass. As the operator knows, the further water must flow through a conduit, the less water can be gotten out without adding more energy. The walls of a conduit whether it be a sewer or channel or forcemaln have small projections protruding in the path of the water, thus causing the water to flow around the obstructions. This causes heat to be generated and energy is lost from the water. When a sewer becomes old and corroded the discharge decreases. What is happening is the sewage or water is losing energy more quickly in an old sewer than in a new sewer. With the above information in mind, we would therefore expect that less

head loss would occur in a very smooth walled plastic forcemain than in an asbestos cement forcemain.

The following classifications could be used for outlining the obstructions encountered in a sewer or forcemain in a sewage works system:

(a) Grit or organic deposits

These may be deposited in the forcemain or sewer and could be due to low velocities allowing grit and organic material to settle out. A velocity of 2.5 fps or greater will keep the deposits in suspension. In a conduit where the velocity is sufficient to prevent settlement of organic deposits a slime layer will build up on the circumference of the sewer. Grit and organic deposits will increase major losses in two ways. First of all, the deposit in the sewer will reduce the effective area of the conduit thus requiring a higher velocity to achieve the same flow. As mentioned previously, the head loss is directly proportional to the velocity head,  $V^2/2g$ . The second way in which grit and organic deposits can increase head losses is due to the fact that the surface over which the sewage must flow is not as smooth as the conduit walls. More turbulence is encountered near the surface of the conduit and thus head losses are increased.

(b) Pitting and corrosion

The inside wall of a sewer may become abraded and pitted by grit constantly being scoured along the conduit or the conduit may be eroded and pitted due to the corrosive action of compounds such as hydrogen sulfide generated from the wastes in the sewer. These pitted areas on the inside surface of the sewer will cause higher head losses to occur.

Minor Losses

These losses occur in localized areas of the sewer system and are usually associated with the fluid changing direction due to an obstruction.

Minor losses occur in the following places in a pressure system such as a sewage pumping station and forcemain:

1. valves
2. elbows and bends
3. wyes
4. tees
5. sudden contractions and reducers
6. sudden enlargements and increasers
7. flow meters
8. inlets
9. outlets

Minor losses occur in the following locations in a gravity system such as a sewer or treatment plant channels:

1. sluice gates, slide gates, etc.
2. change in channel alignment
3. bifurcations
4. sudden contractions (e.g. decrease in channel cross-section)
5. sudden enlargements (e.g. increase in channel cross-section)
6. flow measurement devices (e.g.. flumes, weirs, etc.)
7. manhole inlets or tank entrances
8. manhole outlets or tank outlets
9. screens

Let us examine the loss through a gate valve in some detail. As would be expected, the loss through a gate valve which is wide open is less than a throttle gated valve. This is due to a decreased area through which the flow must pass in a throttled gate. If the area is less, the velocity must increase thus increasing the head loss.

Tables are available for calculating major and minor head losses. These tables will be presented in a later course and the use of such tables will be employed.

Referring to Figure 2 and Figure 3, a sewage pumping station, forcemain and receiving gravity sewer are shown. The sewage pumping station wet well receives flow from a gravity sewer. The flow from the sewer is pumped and discharges into the forcemain which changes diameter once before discharging into the manhole at location h. The pump must be able to supply enough energy to overcome the static lift plus major head losses plus minor head losses.

$$\text{Static lift} = (\text{elevation of forcemain discharge}) - (\text{elevation of water level in the wet well})$$

Major losses:

- losses due to X feet of suction pipe
- losses due to X feet of discharge pipe (small diameter)
- losses due to X feet of discharge pipe (large diameter)

Minor losses:

- entrance loss at suction bell
- loss at gate valve in suction piping
- loss at gate valve in discharge piping
- loss at 90° elbow
- loss at flow meter
- loss at bend
- loss at increaser
- loss at bend
- outlet loss at manhole

The total dynamic head of the pump is the sum of all the values calculated above for the static lift plus the major losses plus minor losses.

Bernoulli's principle states that the total energy remains constant in a system. Thus we may sum up the energy at any point in the system.

Referring to the energy lines (Figure 2 and 3) designated as energy grade line and hydraulic grade line, we see that these lines are downward sloping. The energy grade line is a picture of the available useful energy in the system. This energy is made up of the potential energy as measured from an arbitrary reference datum, the pressure energy and kinetic energy. The hydraulic grade line is simply the potential energy plus the pressure energy. The hydraulic grade line is the height to which the water would

rise if an open standpipe were placed on the forcemain and water were allowed to seek its own level. Note the sudden drop in the energy due to the minor losses at valves, bends, flow meters, etc. The slope of the energy line is greater between d and e than between f and g since the rate of energy loss is greater due to the smaller diameter forcemain between d and e than the larger diameter forcemain between f and g. The energy line is vertical at c since the pump has added energy to sewage flow. The hydraulic grade line is at the centre-line of the forcemain discharge at h since the water is at atmospheric pressure.

Referring to Figure 3, a gravity sewer is shown. The hydraulic gradient is at the water surface in a gravity system. Compare this to our previous pressure system shown in Figure 2 and it can be seen that the flow in the gravity sewer is not under pressure as the forcemain was.

The energy line is again the velocity head plus the pressure head. In a gravity system, the potential energy is not usually considered; that is, the energy is simply termed the hydraulic depth (depth of water from the invert to the water surface) plus the velocity head.

Referring to Figure 3, it can be seen that an inlet loss occurs upon entering the sewer from the manhole at k since the flow must funnel into the decreased cross-section of the sewer. Similar to our pressure system, a uniform loss occurs along the sewer due to friction on the walls of the sewer. Again, an outlet loss occurs when the flow exits from the sewer into the manhole at P. Considering the above, the following factors are taken into account because of losses:

- (a) a downward slope on the sewer is necessary to overcome the friction loss in the sewer as the sewage flows along.
- (b) the outgoing sewer from a manhole usually has a drop in invert elevation when compared to the incoming sewer. This allows for the losses occurring due to the inlet and outlet losses at the manhole. It is necessary to allow more of an elevation difference for a change in sewer direction at a manhole rather than a section of straight sewer. Quite often the manhole is benched to form a smooth transition into and out of the manhole, thus lessening the friction losses.



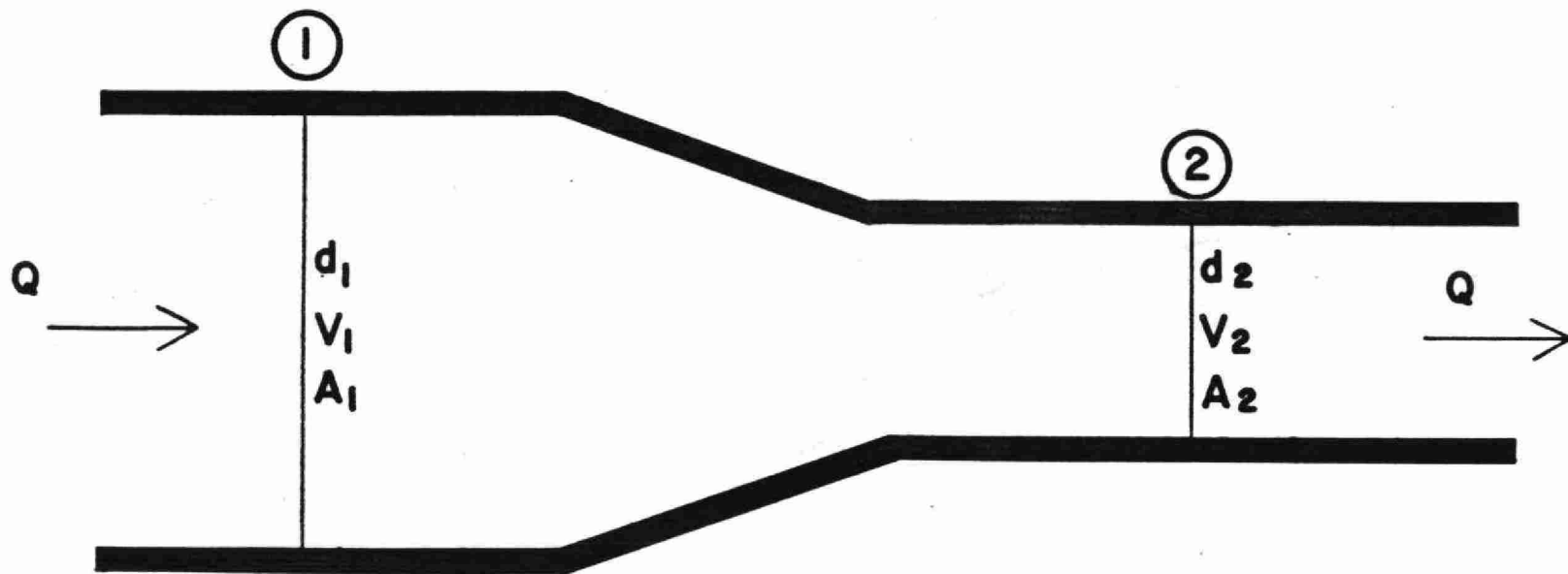
TABLE 1LIST OF SYMBOLS & ABBREVIATIONS

Q	-	discharge in cfs, MGD or GPM
P	-	pressure in psf, psi or ft. of water
V	-	velocity in fps
A	-	cross-sectional area in ft. <sup>2</sup>
g	-	acceleration due to gravity = 32.16 ft./sec./sec.
H <sub>L</sub>	-	head loss in ft.
$\frac{V^2}{2g}$	-	potential energy in ft.
$\frac{V^2}{2g}$	-	velocity head or kinetic energy in ft.
S	-	slope in ft./ft.
WL	-	water level
cfs	-	cubic feet per second
MGD	-	million gallons per day
GPM	-	gallons per minute
psf	-	pounds per square foot
psi	-	pounds per square inch
ft.	-	feet
ft. <sup>2</sup>	-	square feet
fps	-	feet per second
sec.	-	second
Ø	-	diameter in inches, or feet

FIGURE-1

# CONTINUITY PRINCIPLE

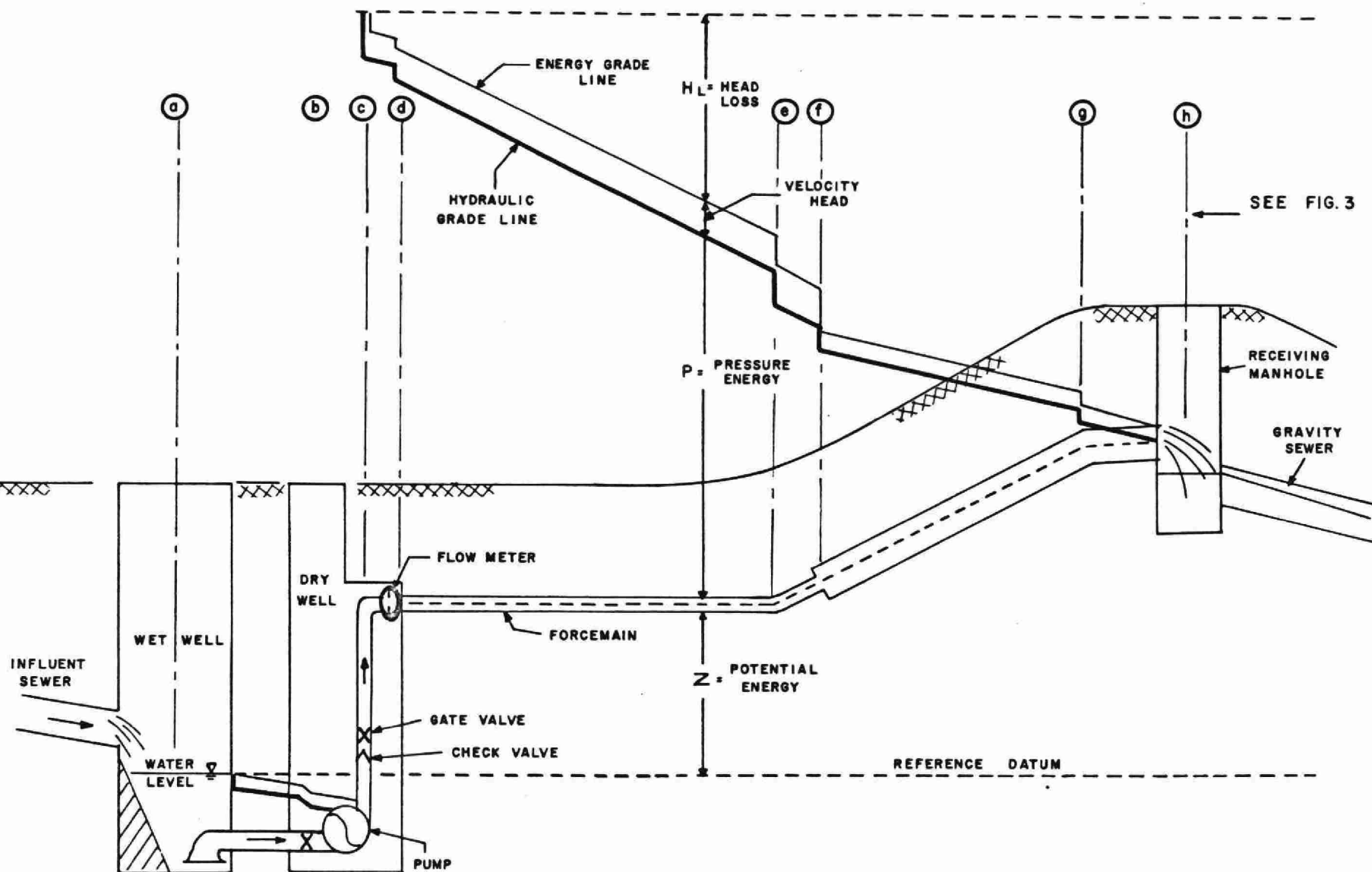
## HYDRAULICS



$$Q = A_1 V_1 = A_2 V_2$$

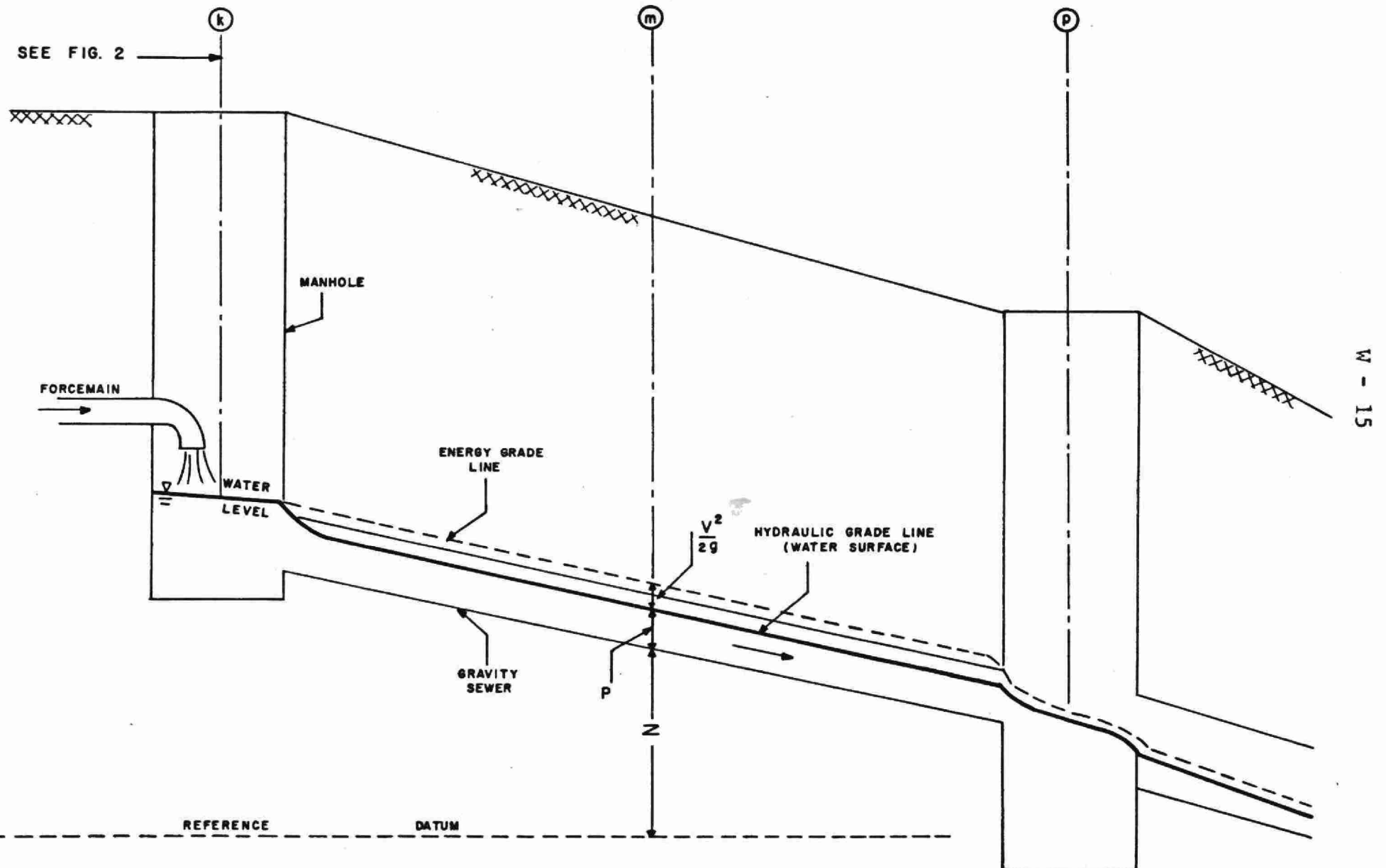
$$V_2 = \frac{A_1 V_1}{A_2}$$

FIG. 2  
BERNOULLI PRINCIPLE



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FIG. 3  
BERNOULLI PRINCIPLE





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